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PHYSICAL OPTICS*

REPORT OF PROGRESS COMMITTEE FOR 1925–26

The field of physical optics has now become so broad, and progress in it so rapid, that it is impossible to give any adequate review in a brief report. Accordingly last year's report was devoted mainly to the new work regarding the structure of complex atoms, as deduced from their spectra. In the present report similar emphasis is placed on the structure of molecules, as interpreted by band spectra,—a subject in which real progress has been made during the past year.

BAND SPECTRA AND MOLECULAR STRUCTURE

(BIRGE)

Because of the greater number of degrees of freedom in the molecule, as compared to the atom, band spectra are far more complex than line spectra. Thus an entire system of bands, sometimes a hundred or more in number, with hundreds of lines to the band, corresponds to a single line, or more strictly to a single "multiplet" of line spectra. Utter confusion is fortunately avoided due to the fact that apparently only a few molecular electronic jumps can be obtained with the experimental means now at our disposal, as compared with the large number of such jumps easily obtained in the case of most atoms. But even with this limitation the known band spectrum of, let us say, the neutral nitrogen molecule, contains at least 50,000 lines. Due to this complexity no compiled data on band spectra have ever been published, Kayser's Handbuch[1] listing merely the data for the heads of the bands. More-

* The Progress Committee on Physical Optics for 1925–26 consists of the following members: R. T. Birge, Chairman, University of California; L. R. Ingersoll, University of Wisconsin; W. F. Meggers, Bureau of Standards; F. L. Mohler, Bureau of Standards; H. M. Reese, University of Missouri; and J. H. Van Vleck, University of Minnesota.

over, the new Kayser and Konen[2] gives no discussion of the theoretical interpretation of bands, according to the quantum theory. Several short articles on this modern interpretation have appeared,[3] and an extended account by one of the National Research Council committees is now in press.[4] Material from this latter report is used freely here, and is gratefully acknowledged.

With a few exceptions, spectroscopic knowledge regarding molecules is confined to those composed of two atoms only. Quantization of the rotation and vibration of such diatomic molecules leads to formulas for the energy which involve the moment of inertia of the molecule, and its variation with the speed of rotation, and also of the frequency of vibration, and the variation of this frequency with the amplitude (or energy) of vibration. The actual energy levels are evaluated by means of the combination principle, just as in the case of line spectra. Because of the complexity of all band spectra, this is the most tedious and difficult portion of the work, but although suggested by the quantum theory, it is quite independent of theory, just as the Ritz combination principle actually appeared before the quantum theory and is merely a statement of numerical relations.

In the band spectra due to homopolar molecules it has recently been found[5] that the successive lines of a series alternate in intensity, and in some cases the weak lines are difficult or impossible even to detect. This has lead to doubts[6] concerning the interpretation, Dieke proposing a new interpretation which would give a moment of inertia only ¼ as large. The question now seems to have been definitely settled[7] by a comparison of the law of force of the molecule, as derived from a study of molecular rotation, and independently from a study mainly of the vibration.[8] The older interpretation gives results checking to less than one or two per cent, while the new interpretation would involve a discrepancy of some 400 per cent in the leading coefficient of the law of force equation. Moreover a comparison of the moments of inertia of molecules of similar mass and constitution leads to striking similarities,[9] so that in cases where the above relation between rotation and vibration cannot yet be applied, because of lack of accurate experimental material, an approximate value of the moment of inertia can be predicted. Such predictions show, for instance, that in the series of the atmospheric absorption bands of oxygen, alternate lines are entirely missing. This is true also in the helium bands, so that the true moments of inertia, as given recently by Mulliken[10] are four times the older values of Kratzer[11] and of Curtis and Long.[12]

It therefore seems probable now that the moments of inertia (I) of diatomic molecules, as calculated from band spectra, cannot be in error by any factor such as 2, 4, ½, or ¼, while the purely experimental error can be made as small as 0.03 per cent by the use of methods of analysis recently developed.[13] As noted, the variation of I with rotation can also be measured. This variation rarely exceeds six per cent,[8] for the speeds of rotation actually obtained.

There has never been any question as to the general accuracy of the frequency of vibration, as deduced from band spectra, i. e., there is no possibility of a missing factor of 2 or 4, as in the case of rotation. The actual frequency is obtained with fair accuracy merely from the spacing of successive bands of what is known as a "progression," each electronic state of the molecule having a different frequency of vibration (ω^n) as well as a different value of I.

But in order to evaluate ω^n with any accuracy, one must be able to assign vibrational quantum numbers to the various bands composing a "system." Recent empirical[14] and theoretical[15] work on the distribution of intensity in band systems has greatly facilitated this procedure, and in the case of most of the well known band systems, such assignments are now known with considerable certainty. Thus in the latest general table of molecular constants[16] there are listed the frequencies of vibration associated with 51 different band systems, due to 28 different diatomic molecules, and the moments of inertia associated with 41 different band systems, due to 29 different diatomic molecules.

The application of the new quantum mechanics to molecular structure[17] may change the calculated frequency of vibration of all molecules by a very small amount. The only possible change in the moment of inertia is in general quite negligible.

Building up a system of electronic energy levels for molecules, similar to that for atoms, is based mainly on the observed occurrence of a set of identical vibrational energy levels (identical values of ω^n as a $f(n)$) in two different band systems. This was first done by Heurlinger[18] in the case of the red and violet CN bands. Birge[19] later found similar relations between three nitrogen band systems, and as a result of the work of several investigators it is now possible to set up a fairly complete system of levels for the molecules CO, N_2, O_2 and NO.[20] Recent work on the absorption spectra of the molecules just mentioned[21] has been of great aid in this connection, for bands found in absorption in a cold or fairly cool vapor *must* have as a lower energy level the normal state of the molecule.

It may be noted in passing that the ability to assign a given system of bands to a definite molecule in a definite energy state may be of importance in other fields. Thus it is now known that the comet-tail bands are due to CO^+, excited with 2.52 volts of electronic energy and with vibrational energy up to 1.7 volts. This information is of value in work on the theory of comets.

Hydrogen, as the simplest of all molecules, is the most important from a theoretical standpoint. After a great deal of work by many investigators, Dieke and Hopfield[22] have now obtained and analyzed, in both emission and absorption, the ultraviolet spectra of hydrogen, and have thus definitely established the first three electronic levels of the molecule (the excited levels being at 11.1 and 12.2 volts) with the accompanying frequency of vibration of each. Because of the peculiar structure of the bands (composed of Q branches only) it is impossible to evaluate the moment of inertia. The connection between the known bands of hydrogen in the visible spectrum[23] and these ultraviolet bands is still not clear.

One important practical result of band spectra analysis is an evaluation of the heat of dissociation D of the molecule. This was first done roughly, in the case of iodine, by Franck.[15] The first accurate determination was in the case of oxygen, by Birge and Sponer.[20] These latter investigators also obtained approximate values of D for CO, CO^+, N_2^+, O_2^+, and NO. Sponer[24] had earlier evaluated the heat of dissociation of N_2 as 11.4 volts, from the energy of "active nitrogen," assuming this to be atomic nitrogen,[25] and this value she has now verified by recent (unpublished) work on the absorption and emission spectra of nitrogen. The writer believes that it must now be considered as settled that "active nitrogen" is atomic nitrogen, that the carrier of the strongest afterglow bands is a nitrogen molecule excited with 11.4 volts of energy and that this energy equals, to a very close approximation, the heat of dissociation of nitrogen. It may be noted that in this case, as well as the others just mentioned, the heat of dissociation is too large to be obtained by chemical methods. Meanwhile Witmer[26] had obtained a value of D for H_2 of 4.3 to 4.4 volts (99,000 to 101,500 calories), by means of an analysis of the Lyman bands, and the later analysis of Dieke and Hopfield proves that this value is correct.

Another interesting consequence of band spectra analysis is the conclusion that molecules cannot acquire vibrational energy directly, as a result of electron impact, but can acquire such energy indirectly, sometimes in amounts great enough to lead to dissociation. The impacting electron apparently displaces one of the molecular electrons, and as

a result the vibrating nuclei are suddenly governed by a new law of force, and the conditions may be such as to lead to a large amount of vibrational energy.[27] If this results in dissociation, the products of dissociation are probably one normal and one excited atom.[28] Thus a molecule *cannot* be dissociated by direct electron impact of energy equal to the heat of dissociation, but must be given an energy in excess of this (although sometimes the excess amount is very small), dissociation occurring as a secondary result under certain conditions.

Recent work on band spectra has led Birge[29] to the generalization "The energy levels associated with the valence electrons of molecules agree in all essential aspects with those associated with the valence electrons of atoms." In particular, molecular levels can be characterized as S, P, D, etc., as in the case of atoms, and have a similar multiplicity. The law of spacing of electronic levels is often, if not always, the usual Rydberg or Ritz law of line spectra. Mulliken[30] had done earlier work along this line, and with the above generalization as a basis, has since developed a complete systematization of band spectra.[31] The results are very striking, and lead to the hope that one can determine unambiguously the quantum characteristics of each electronic level from an analysis of the band spectra associated with it, just as such characteristics are obtained in the case of atoms mainly from the complex Zeeman effect. The whole matter is so involved that neither the details nor the general conclusions can conveniently be stated in a report like this.

The major problem of the actual structure of the chemical bond still remains unsolved. Mulliken[30] has taken over the Lewis-Langmuir idea of "octets" in the case of CO, N_2, etc., and this was assumed by Birge in his analysis of the spectra of carbon monoxide.[32] The similarity of CO and the "corresponding" atom Mg is very striking. The octet idea assumes that at least eight electrons (ten in CO) are held more or less in common by the two atoms, and may have quite different quantum characteristics from the atomic orbits. Birge and Sponer[20] have however shown that firmly bound molecules like O_2 can be dissociated by light absorption in a continuous (adiabatic) process, and in fact behave in this respect identically like loosely bound molecules such as I_2.[33] Kemble[34] believes that this indicates that *all* these molecules consist merely of two atoms with more or less distorted orbits, but with the original quantization of the atomic structure, as is probably the case for He_2.[10] If true, this would contradict the entire "octet" idea. Kemble, in this same reference, presents a considerable amount of new

unpublished work on the general problem of molecular structure. Hund[35] also has written an important theoretical paper, applying to molecules the same concepts he had previously[36] worked out so successfully for complex atoms.

In regard to work on multi-atomic molecules we mention merely the following out of many papers,—Cooley[37] has obtained in some detail the infrared absorption spectrum of methane, and Dennison[38] has given a theoretical treatment of the data, and has later discussed CO_2 and NH_3.[39] Henri and Schou[40] from an analysis of the spectrum of formaldehyde have for the first time obtained detailed evidence of the existence of *double* rotational quantization, connected with the two chief moments of inertia of this molecule. Sleator and Phelps[41] have obtained the line structure of the near infrared absorption bands of water vapor. Schaefer and Phillips have made quantitative deductions as to the form of the CO_2 molecule from data on the infrared spectrum, in a paper[42] which has since been critically discussed by Eucken[43] and by Dennison.[44]

THE NEW QUANTUM MECHANICS

(VAN VLECK)

The past year has been an outstanding one for theoretical physics because of the development of a new quantum mechanics, the need for which has long been apparent from deficiencies of the old quantum theory. This new dynamics has revolutionized the quantum theory in an amazingly short time, and has been evolved in three different mathematical forms respectively by Born, Heisenberg, and Jordan, by Dirac, and by Schrödinger.

In the theory of Born, Heisenberg, and Jordan,[45] the Hamiltonian form of the equations of motion is retained, but coordinates are to be regarded as matrices rather than as series. Each element in a matrix is identified with a transition between two stationary states of the old theory, and has an imaginary exponential factor determining the frequency and an amplitude factor determining the transition probability. The quantum conditions enter as measures of the non-commutativeness of the order of multiplication, and take the form $\mathbf{pq}-\mathbf{qp}=h\mathbf{1}/2\pi i$ for a system with one degree of freedom. The extensions to more degrees of freedom are easily obtained by analogy with the Poisson bracket expressions of classical dynamics.

Dirac's method[46] is based on "angle variables," and is useful in special problems, but its application is often difficult because of the necessity of finding the proper contact transformation.

The most recent form of the new quantum dynamics is that embodied in the wave equation of Schrödinger,[47] which bears an intimate relation to the phase-waves of de Broglie.[48] Schrödinger finds that the energy levels E to be used in the Bohr frequency condition are the "characteristic values" (*Eigenwerte*) of a certain partial differential equation, which in the case of a single particle subject to a potential $V(x, y, z)$ takes the form

$$\frac{\partial^2\psi}{\partial x^2}+\frac{\partial^2\psi}{\partial y^2}+\frac{\partial^2\psi}{\partial z^2}+\frac{8\pi^2 m}{h^2}(E-V)\psi=0$$

By the characteristic values are meant the values of the parameter E for which there exist solutions ψ which remain finite throughout all space and which vanish properly at infinity. Using the technique given in Courant-Hilbert's "Methoden der Mathematischen-Physik," Schrödinger[49] and Eckhart[50] have shown that this wave theory is in accord with the matrix method, and each element of a matrix can, in fact, be expressed as a volume integral involving E and ψ.

Although the three forms of the new mechanics give similar final results, the consensus of opinion appears to be that the Schrödinger method is more powerful than the matrix one, but the formulation in matrices shows a closer resemblance to the old quantum theory. It is commonly conjectured that the Schrödinger form is more "physical" than the others because it involves a "characteristic function" ψ which is in the nature of a wave, and that this function will be associated with some property of the electron. Until a more specific interpretation for ψ is developed, such speculations are rather indefinite, but Born's theory[51] of collisions and a paper by Dirac,[52] as well as some of Schrödinger's own work,[47] are steps towards removing the ambiguity. Likewise it is not at present at all clear what degree of physical reality is to be ascribed to the stationary states of the old quantum theory, but in any case the Bohr frequency condition still holds.

The advantages of the new quantum mechanics are numerous. In the first place with the matrix method the Bohr frequency condition is no longer necessarily a separate postulate and instead can be proved a consequence of the quantum conditions and the Hamiltonian form. The new quantum dynamics incorporates logically and simultaneously both frequency and intensity, whereas the old quantum theory gave specific results only for frequencies, and hitherto intensities could only be evaluated asymptotically by appealing to the correspondence principle. The various aspects of the correspondence principle are automatic

consequences of the new mechanics, whereas in the old theory they were separate new hypotheses except as regards frequencies. The explanation of dispersion is more satisfactory then previously, as the new mechanics gives unambiguously[53] the Kramers dispersion formula and removes the "long wave length difficulty." By the latter term is meant the fact that in the old theory the Kramers dispersion formula implied an "unclassical" reaction to incident waves of all wave lengths while at the same time Epstein's calculation of the Stark effect presupposed a classical behavior for infinitely long impressed waves. The new mechanics gives[54] the various selection principles and the intensity rules previously developed more or less empirically by Sommerfeld, Dorgelo, Kronig, Russell, Hönl, and others. It also yields a high degree of "spectroscopic stability" which is of great importance in connection with the polarization of resonance radiation,[55] and which greatly improves the quantum theory of dielectric and magnetic susceptibilities.[56] The Compton shift in wave length has been derived with the new mechanics by Dirac.[57]

The new quantum mechanics has had an uncanny and gratifying success in giving the same energy values as the old theory whenever the latter was in accord with experiment, and different values when it was not. The new dynamics still yields the Balmer formula[58] for the simple hydrogen atom in which relativity corrections are disregarded. The expression for the first order Stark effect in hydrogen is the same as that in the old theory, but with the great advantage that it is no longer necessary to exclude arbitrarily certain states because of collision difficulties. The second order terms in the Stark effect are somewhat modified,[59] and possibly in better agreement with experiment. Schrödinger[47] and Epstein[59] find the wave theory gives excellent results on the intensities of Stark effect components. It is probable that mathematical investigations in progress by European physicists will show that the new mechanics accounts numerically for term values in the neutral helium spectrum, a great stumbling block for the old quantum theory. In this connection mention must be made of a very important recent paper by Heisenberg[60] on the differences between singlet and triplet spectra. These differences were previously a mystery as they are far too large to attribute to internal spins of the electrons. Heisenberg shows that they are intimately related to the Pauli "exclusion principle"[61] and are due to a peculiar type of resonance effect associated with electron interchanges.

Turning now to molecules of the type which can be treated as ordinary rotating dipoles, it is found[62] that the new mechanics gives the familiar Deslandres and Kratzer formulas for band spectra like the old theory except that the rotational and vibrational quantum numbers must both be given half integral instead of integral values. A logical basis, in fact, is furnished for the "half quantum numbers" which hitherto were an enigma.

Another epoch-making development of the past year is the advent of the "spin electron." Pauli's[61] analysis of Stoner's model of the periodic table showed that there must be four quantum numbers per electron, and Uhlenbeck and Goudsmit[63] made the fruitful hypothesis that the fourth degree of freedom is due to internal spins. The possibility of such spins had previously been intimated from other standpoints by A. H. Compton,[64] and Kennard.[65] The spinning electron appears to be quite generally accepted, although it encounters some serious difficulties.[66] It has furnished an origin for the anomalous ratios of magnetic moment to angular momentum and for the mysterious optical and x-ray doublets which conformed to the relativity formula even though they could not logically be ascribed to relativity. The work of Thomas[67] and Frenkel[68] taken in conjunction with that of Heisenberg and Jordan[69] shows that "spin doublets" have to the first order the same separations as the relativity doublets of the old quantum theory. Thomas and Frenkel prove that an apparent error by a factor two is removed by correct application of the relativity theory. Heisenberg and Jordan[69] show that with the spinning electron the new quantum mechanics really gives Landé's g-formula for the anomalous Zeeman effect. This must be regarded as one of the greatest triumphs of the new dynamics. Without the internal spins we would have only the normal Lorentz separation. The new interpretation for the hydrogen fine-structure is startling and is especially interesting since it was proposed empirically by Goudsmit[70] and by Slater[71] even before the advent of the new mechanics. The latter involves half-integral values for the azimuthal quantum number, and so gives a relativity fine-structure not at all in accord with experiment unless account is taken of the internal spin of the electron. These new relativity corrections, however, when augmented by corrections for the internal spin, give to the first order the same fine-structure levels as those of the old quantum theory without the spinning electron. The new mechanics has at the same time the great advantage that strong components found experimentally are no longer contrary to the selection

principle. Also it is not inconsistent with the observation of a Paschen-Back effect in hydrogen,[72] and brings the hydrogen spectrum into much closer accord with the spectra of other elements. In short, both the coincidences and differences between the results of the old and new quantum mechanics, especially in hydrogen, are most remarkable.

PENETRATING RADIATION

(BIRGE)

The problem of the properties and origin of the penetrating radiation which is responsible for at least a portion of the residual ionization of the atmosphere is of great importance in several domains of physics. The subject has been extensively investigated during the past fifteen years, among those most prominently connected with the work being Hess and Kölhorster, and more recently, Millikan. A comprehensive review of work done up to 1924 is given by Wigand,[73] together with a bibliography of some 125 articles. Millikan and co-workers, continuing work first briefly reported in 1922, have during the past year obtained new and important results which have greatly stimulated interest in the subject. These results were first announced in an address before the National Academy of Sciences in Nov. 1925,[74] and the actual data are now being given in a series of articles[75,76,77,78]. This work has, however, been subject to criticism by Hess,[79] Hoffman,[80] and Kölhorster,[81] inspired partly by certain unfortunate newspaper reports which accompanied the matter. A comparison of the results of Millikan and of previous investigators is given by Wright,[82] and also in the articles just quoted. Recent data by Myssowsky and Tuwin,[83] and by Hoffman[80] may also be cited, as well as a discussion by Běhounek.[84]

Without attempting to enter the controversy, which is concerned partly with priority considerations, and partly with the actual results, we merely note that all of the recent work indicates definitely the presence of an extremely penetrating radiation (coefficient of absorption 0.18 per meter of water according to Millikan) of cosmic origin. Millikan's recent results indicate that this radiation comes at a constant rate, day and night, and fairly equally from all directions of space, while Kölhorster, in 1923, obtained results indicating that it comes more particularly from the direction of the Milky Way.

Assuming a particular relation between wave length and coefficient of absorption,[85] Millikan obtained 4×10^{-4} to 6.7×10^{-4}A as the wave length range. Jauncey and Hughes pointed out[86] that if Jauncey's formula[87] had been used, the result would be 2.4 to 3.2×10^{-3}A. In view of the very long extrapolation and the uncertainty as to the correct

formula, the calculated wave lengths do not seem of sufficient weight to be considered as bases for theories regarding the origin of the cosmic rays, as has been done by Millikan,[74] Jeans,[88] Jauncey and Hughes,[86] and Condon.[89]

RELATIVITY

(BIRGE)

The results of Miller's ether drift experiments were mentioned in last year's report. The present year has been one of continued interest in this subject. Miller has not yet published the full details of his recent work, but has discussed the subject at the Kansas City (Dec. 1925) meeting of the American Assn. for the Advancement of Science.[90] Miller's original assumption of a direct determination of ether drift has been criticized by Eddington[91] and by Swann,[92] and the most probable explanation of the experimental results is thus far rather obscure. More recent summaries of the present status are given by Strömberg[93] and by Lodge,[94] the latter article being answered by Miller[95] in his latest published statement on the subject. Thirring[96] and Weber[97] both give a direct criticism of Miller's experimental results, while Page and Sparrow[98] have suggested a possible explanation of the results. Very recently R. J. Kennedy (Proc. Nat. Acad. Sci., *12*, p. 621; Nov. 1926) has repeated Miller's work, with an improved form of apparatus, and has obtained *no* evidence of ether drift.

Meanwhile the Trouton and Noble experiment has been repeated by Tomaschek,[99] at an altitude of 11,400 ft., and by Chase[100] at low altitude but with very great care. Both observers obtain negative results, Chase's accuracy being ± 4 km/sec. A general review of all the experimental tests of relativity is given by Joos[101] and also by Eve.[102] The latter account is particularly clear, and contains among other things a report of St. John's address at the Kansas City meeting summarizing the data on the subject of the red displacement of spectral lines. The most conclusive evidence here seems to be Adam's observations on the companion of Sirius, described in detail in last year's report.[103] The solar observations are not so convincing, Burns and Meggers[104] having concluded that it is impossible at present to say whether or not the predicted red shift resulting from gravity is present, while St. John's latest results, as reported at Kansas City, are in agreement with prediction. The most recent published paper by St. John[105] contains only his older results.

The present status of this whole subject seems to be that, aside from Miller's own work, and the displacement of solar lines, all of the experimental tests of relativity are reasonably well confirmed.

LINE SPECTRA AND ATOMIC STRUCTURE

(MEGGERS)

Information concerning structures of atomic spectra was fully reviewed in the last report and attention was called to the fact that little or nothing was known of spectral structures for the heavy atoms, and, except for some of the lighter elements, no classifications extended beyond the first spark spectrum. With the aid of some general laws of spectral structures and their relations to the periodic arrangement of the chemical elements, rapid progress is being made in the analysis of complex spectra and it is impossible in the present report to do more than simply mention the spectra in which new relations have been discovered during the past year.

New contributions to the analyses of arc spectra have been made for the following elements: A,[106] Au,[107] Be,[108] Br,[109] Cb,[110] Cl,[109,111] Cu,[112] Hg,[113,114] I,[109] Ne,[115] Mn,[116] Mo,[110,117] P,[118] Pb,[119,120] Pd,[121] Pt,[122,123] Ru,[123,124] Zn,[114,120] Zr,[110] Y.[110]

The first spark spectra or spectra of singly ionized atoms have been more or less extensively investigated for the following chemical elements: B,[125] Be,[108] Cb,[110] Hg,[126] K,[127] La,[128] Li,[129] Mo,[110,117] O,[130] Pd,[121] Zr,[110] Y.[110]

Some important features of the second spark spectra characteristic of doubly ionized atoms have been recognized for the following elements: C,[125] Ga,[126] In,[126] La,[131] Ti,[132] Tl,[126] Y[131] and Zr.[133]

The first regularities among spectral lines from trebly ionized atoms were announced for a small list of elements. They are Ce,[131] Ge,[126] Pb,[126] Sn,[126] Zn.[131]

Oxygen is the only element for which the lines of the fourth degree of ionization were identified[134] during the past year and the "lithium-like" doublet characteristic of quintuply ionized oxygen was also discovered.[134]

In connection with these investigations of spectral structures new Zeeman-effect observations were made with Cu,[112] Mo,[117] Pb[119] and Ru.[124] Because of the definiteness with which such observations fix quantum numbers and completely specify the spectral terms it would appear that more extensive study of the spectral lines in a magnetic field is desirable for the complete description and classification of spectra.

Accurate measurements of the relative intensities of spectral lines have been reported for the so-called doublets of He[135] and for certain multiplets in the spectrum of iron.[136] Burger has found that the He doublets have an intensity ratio of 8:1, which is interpreted to mean that the groups are in reality triplets with the intensity relation of

5 : 3 : 1, but the components with intensities proportional to 5 and 3 are so close that thay have never been resolved. If this explanation is correct it provides neutral He with odd multiplicities (singlets and triplets) and thus removes the only apparent exception to the spectroscopic alternation law, that odd values of r occur for even values of Z.

The Heisenberg-Hund theory of spectral terms and electron configurations was outlined in the last report. During the past year it has been applied in detail to the spectral structures of a considerable number of elements, permitting a satisfactory interpretation of the empirical analyses and in many cases predicting terms and relations which have made it easier to extend the classifications of spectral lines. The theory is reviewed and methods of applying it are very well illustrated in papers by Fowler and Hartree,[137] by Laporte[138] and by McLennan, McLay and Smith.[139] An interesting theoretical paper on this subject by Slater[140] has just appeared.

THE PHOTOELECTRIC EFFECT

(REESE)

Mohler, Foote and Chenault[141] have continued the work of Foote and Mohler[142] with caesium vapor, mentioned in the report of last year. They find not only the sharp maximum of ionization at the 1^2S limit, the effect decreasing with shorter wave lengths as previously reported, but also the ionization previously found on the longer wave length of the principal series from 1^2S–4^2P to 1^2S–9^2P. On the whole, their results seem to bear out completely the interpretation, in terms of the Bohr theory, that had been put upon the region of continuous absorption shown by monatomic metallic vapors beyond the principal series limit.

Ives and Johnsrud[143] have continued work on the effect of temperature upon the saturation photocurrents, working with potassium, rubidium and sodium,—at first with rough sublimated surfaces. Using yellow light (filter) they found that from −180°C to +20°C the current increases with temperature almost linearly. Using blue light, the variability is less, but is in general in the same sense. However, sodium excited by blue or white light gave nearly the same value of the current at both extremes of temperature, with a flat maximum about −80°C. This last may explain Burt's[144] failure to find any temperature variation for sodium. Ives and Johnsrud also tried a specular potassium surface, formed by melting and slowly cooling the metal. In this case, variability with temperature and color of the exciting light was found to be in the same sense, but much more pronounced.

The same authors, Ives and Johnsrud, in another paper[145] give some results obtained with rubidium films deposited "spontaneously" on glass surfaces in an evacuated space containing the metal, which are interesting, though their theoretical significance is not obvious.

H. Dember[146] has experimented with an aluminum plate which when exposed simultaneously to ultraviolet illumination and cathode ray bombardment, sends a greater saturation current to a platinum gauze anode than the sum of the currents obtained under each of the stimuli separately. The effect of the cathode rays is probably to push the photoelectric threshold toward greater wave lengths.

C. B. Kazda[147] describes a careful experiment to find the threshold for pure mercury. The liquid is carefully purified, and the surface renewed intermittently by overflow. Illumination is by the bright lines from a Cooper-Hewitt quartz mercury arc. Saturation currents per unit light intensity are plotted against wave length, and the curve extrapolated. The threshold is given as 2735A.

A. E. Woodruff[148] gives results obtained with platinum when given different heat treatment. He concludes that the increase in photoelectric sensitivity on moderate heating is caused by removal of a surface layer, in accordance with the theory of Wiedmann and Hallwachs, but that the decrease after more extreme heating is not a result of the removal of gas from the body of the metal, but rather of the formation of a different type of surface layer. He reports the following strange phenomenon as occuring in certain conditions of the metal: a retarding potential of 2 volts, momentarily applied, destroyed for the time being, all response to mercury arc excitation, but the original sensitivity was immediately resumed when an accelerating potential was again applied. In all cases, an apparently complete loss of photoelectric sensitivity to the mercury arc seems to be caused by a change in the threshold value to very high frequency.

T. H. Harrison[149] undertook, using tungsten and platinum, to measure for the same sample the thermionic and the photoelectric work-function. For tungsten definite results could not be obtained, but for platinum the photoelectric was in every case found to be larger than the thermionic. So far as the effects of varying heat-treatment are concerned, his results were in general agreement with those of Woodruff as given in the paper cited above.

CRITICAL POTENTIALS AND DISCHARGES IN GASES

(MOHLER)

A full account of work in this field up to about March, 1926, is given in a recent book by Franck and Jordan.[150] The developments in the field of band spectra (l.c.) have given new significance to the data on critical potentials of diatomic molecules. Studies of the excitation of band spectra by electron collision in N_2,[24,151,152] O_2[153] and CO[154] in general confirm and supplement the energy level schemes obtained by spectrum analysis. Results of magnetic analysis of ions produced by electron collision give information both as to the energy required to produce molecule and atom ions and as to the relative probability of the processes involved. Results on H_2,[155,156] O_2[157] and N_2[158] show that molecule ions are produced at the first ionization potential. Production of atom ions is much less probable but apparently N^+ and O^+ are produced directly by electron collisions at higher voltages. Blackett and Franck[159] find conclusive evidence that excited hydrogen atoms are produced directly by electron collisions with molecules by the observation that atomic spectra are produced under conditions where secondary excitation processes are eliminated. Presumably H^+ also is produced to some extent though the positive ray results do not show it. Experiments on the nitrogen spectrum give similar results.[160]

An important relation connecting the ionization potentials and spectroscopic data is the identity of the work required to remove an electron from a molecule and dissociate the molecule ion, as compared with the work of dissociating the molecule and then ionizing one of the atoms (Birge and Sponer[20]). Computed values of both molecular ionization potentials and band excitation potentials seem to agree with observed values within the experimental error of about 0.5 volts. Is exact agreement to be expected? Computations refer to states of zero vibration energy while theoretical considerations, as discussed in the section on band spectra, indicate that an electron in producing excitation will in general change the state of vibration. The experimental evidence of dissociation by electron excitation indicates that in some instances the vibration change is very large. More accurate electrical measurements should give interesting information on this point.

Direct evidence concerning the process of recombination of ions and electrons is of great theoretical interest. By use of the principle of detailed balance[161] one may correlate the continuous absorption beyond a series limit with the probability of recombination as a function of the electron speed. Measurements of absorption coefficients[162] and of photo-

ionization (photoelectric effect l.c.) indicate that recombination is improbable except when the electron speed is very low. On this assumption Miss Hayner[163] explains a peculiar intensity change in the afterglow spectrum of mercury as observed with a high speed sectored disk and commutator. Some lines (high members of the subordinate series) are absent immediately after the voltage is cut off and then reappear for a short time. This reappearing spectrum is ascribed to recombination for, it is pointed out, electrons must first lose their speed during the dark period before recombination is probable. Lord Rayleigh's[164] observations on the luminosity outside the discharge space in mercury can be explained in the same way.

The phenomenon of formation of negative ions by molecules with an electron affinity in the presence of electrons should be analogous to recombination of ions and electrons. A method is described by Mohler[165] which is adapted to measuring negative ion formation as a function of the electron velocity and the results indeed point to the conclusion that only very slow electrons form negative ions. Experimental evidence as to the spectrum associated with the process of negative ion formation is as yet open to question.[166] The electrical experiments indicate that for both the non-polar molecule I_2 and the polar molecule HCl negative ions are not produced as a direct result of ionization by electron collision. This is in accord with theory but conflicts with the usual interpretation given to critical potentials of the hydrogen halides.

We are unable to report in detail what is probably the outstanding development in electronics. Dymond[167] has measured the angular distribution of electrons scattered by helium and found that there are preferential directions depending on the electron speed, quite like what has already been found by Davisson and Kunsman[168] in the case of solids. Quite independently Born discovered that such phenomena are to be expected and can be predicted on the basis of the new quantum mechanics (l.c.).

POLARIZATION BY ELECTRON IMPACT

(INGERSOLL)

Ellett, Foote, and Mohler[169] have measured the polarization in the radiation resulting from the impact of a unidirectional beam of electrons on the atoms of a vapor at low pressure, in the absence of a magnetic field. The experiment is one of promise, for it would seem to afford a means of probing into the dynamics of collision between electrons and atoms. No adequate quantitative theory (of the polarization phe-

nomenon) has, however, yet been given. Mercury vapor shows some 30 per cent polarization, but in a direction opposite to that predicted by theory. Sodium shows no polarization, which is in agreement with the findings of Kossel and Gerthsen.[170]

X-RAY SPECTRA

(INGERSOLL, BIRGE)

Of the very large number of recent papers in this field, we mention merely a few relating to certain special topics. Bergen Davis and his co-workers[171] made the first precision measurements of the index of refraction of crystals for x-rays, by grinding the crystal surface to a certain critical angle with the natural cleavage surface. Siegbahn and his co-workers[172] first obtained the direct refraction of x-rays by a prism, the beam being slightly bent *away* from the base, corresponding to an index of refraction less than unity. Davis and Slack[173] then developed a precision method for measuring this direct refraction. The observed values of the index of refraction agree well with those calculated on the classical theory of dispersion.

Compton and Doan[174] have recently secured x-ray spectra from an ordinary ruled reflection grating. Working at a glancing angle of less than 25 minutes of arc and using a grating of comparatively coarse ruling (500 lines/cm) they made measurements of the $K\alpha_1$ line of molybdenum which differ by only a fraction of a per cent from the accepted values. Thibaud[175] has obtained similar results for the $K\alpha$ line of Cu, and de Broglie and Thibaud[176], by means of total reflection of x-rays, have shown the variation of the index of refraction in the neighborhood of an absorption discontinuity of the reflector.

The most interesting property of x-rays is possibly that indicated by the Compton shift, mentioned in last year's report. Sharp[177] has since made precision measurements of the change of wave length, accurately checking the theoretical expression, but Beck,[178] using the older quantum mechanics and Dirac,[57] using the new quantum mechanics, have derived the same formula so that this phenomenon can no longer be considered as evidence for the extreme light-dart theory.

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THE EFFECT OF EXPOSURE TO X-RAYS UPON THE THERMOLUMINESCENCE OF SOME SYNTHETICALLY PREPARED MATERIALS*

By Frances G. Wick and Mabel K. Slattery

The effects of x-rays in restoring activity to thermoluminescent minerals[1] which have been deactivated by heating is well known.[2] In general it is assumed that this ability to fluoresce at high temperatures is due to the presence of traces of impurities, the spectral nature of the light obtained being dependent upon the impurity involved. In some cases it is possible by a study of the light emitted to identify the impurity present. Identification of the impurity, however, is not a simple matter. Sometimes several "activators" are present in a given crystal—the resulting spectrum being very complex. The amount of impurity is too small to be detected by ordinary chemical analysis: as a result a quantitative estimate is impossible. It seemed advisable, in view of the uncertain composition of the natural materials to make some thermophosphors of known composition. From these it might be easier to deduce the quantitative effects due to exposure to x-rays.

Several synthetically prepared substances which showed luminescence in a cathode ray tube were examined for thermoluminescence. They showed no effect upon heating before exposure to rays. After exposure to x-rays, varying from 1 to 2 hours, from a tube run at 2 m.a. and about 45 KV, these same samples showed a luminescence when heated: the color of the thermoluminescence usually corresponding to that observed in the cathode ray tube. Table 1 gives a list of the observations.

Of these substances, $CaSO_4$+Mn seemed the most desirable for further study, since it gave a high color which could be easily matched by combining color screens. These samples would not easily be affected by exposure to the moisture of the air as were the samples of CaO.

*The work included here was undertaken as a sequel to a study of "The Effect of X-Rays on Thermoluminescence" (calcites and fluorites), Wick, J. O. S. A. & R. S. I., *14*, p. 33; 1927.

[1]Activation of the natural crystal possibly was due to radioactive transformations or even exposure to the new cosmic ray over very long periods.

[2]Bailey, Phys. Rev., *2*, *24*; p. 495.

Two samples were made, one containing twice as much manganese as the other. The method of preparation was to evaporate to dryness a mixture of $CaSO_4$ with $MgCl_2$ and NH_4OH. This was sifted through wire gauze 70 mesh to the inch and then heated to a bright red heat for about an hour in a quartz crucible with a blow torch. The porous mass

TABLE 1.

Material	Thermoluminescence Unexposed	(Temp. approx. 250°C) Exposed 1–2 hours
Tested pure $CaCO_3$	none	none
Tested pure CaO	none	none
CaO+Erbium	none	violet and blue
CaO+Samarium	none	orange
CaO+Dysprosium	none	yellowish white
CaO+Neodymium	none	faint blue
Tested pure $CaSO_4$	none	none
$CaSO_4$+manganese	none	bright green

resulting was pulverized and again passed through 70 mesh gauge to insure uniformity of size and homogeneity of material. It was found from previous experiments with natural thermoluminescent materials that the size of the grain affected the luminescence. Sample *A* contained 25 cc .01 Molar solution of $MgCl_2$; 4 H_2O for 20 grams of $CaSO_4$. Sample *B* contained 50 cc of the same solution for 20 grams. Sample *A*—1 : 460. Sample *B*—1 : 230.

Calculation shows sample *A* to contain one atom of manganese to about 500 molecules of solvent $CaSO_4$. Sample *B* has about 250 molecules of solvent to each atom of activator. A glance at Fig. 2 will show that the concentration for optimum brightness is probably nearer the higher concentration.

Spectroscopically the luminescence obtained on heating was a green band extending from 4800 to 5600 A. At comparatively low temperatures (200–300°C) the decay of luminescence was very rapid, but at 120° the fading was slow enough to make a determination of curve of decay possible. The method of observation is described in a previous paper.[3] Measurements were made on Sample *B* (1 : 250), exposed for 1 hour to the x-rays. Fig. 1 shows the decay to be of the persistent[4] type.

[3] Wick, J. O. S. A. & R. S. I., *14*, p. 33; 1927.
[4] Nichols and Howes, Nat. Acad. Sci., Proc., *4*, pp. 305–318.

The effect of temperature to which the substance was treated, after exposure to x-rays, upon the brightness of the maximum was observed.

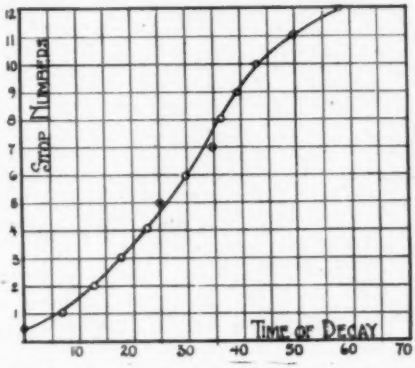

FIG. 1. *Curve of thermoluminescence decay. Mn in $CaSO_4$ (1:250): temperature 120°C.*

Fig. 2 shows the results. In general the curve approximates a straight line, for both samples. Increasing the length of exposure increases the brightness of the maximum at a given temperature, as can be seen by comparing the two curves for *B*.

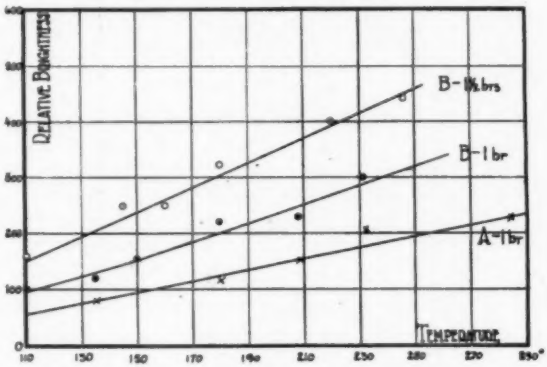

FIG. 2. *Curves of maximum brightness; temperature varied; Mn in $CaSO_4$; A = (1:500); B = (1:250)*

To examine the effects of varied lengths of exposure on the maximum brightness observations were made at different temperatures on both samples. For the sample containing the smaller amount of manganese at the temperatures 170° and 263°C the brightness is seen to increase gradually with the length of exposure but a saturation is

reached in about 50 minutes. At a higher temperature (285°C) no maximum is reached within the hour for either sample. Fig. 4 is for

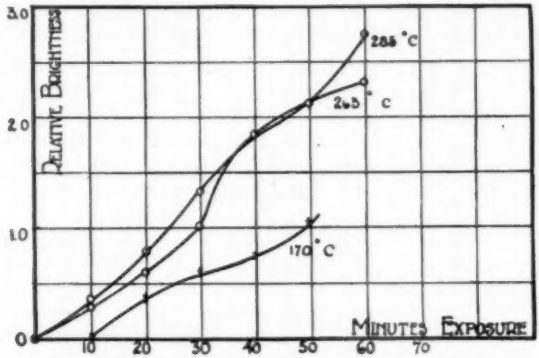

FIG. 3. *Curves of maximum brightness; lengths of exposure varied; Mn in* $CaSO_4$ *(1:250).*

Sample *A* (1 : 500). Fig. 3 for *B* (1 : 250) shows that a longer exposure would be required to reach a saturation due to the increased amount of activator.

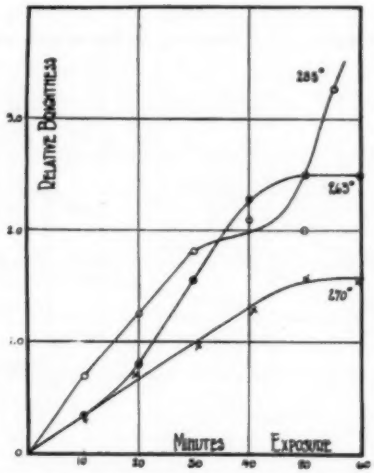

FIG. 4. *Curve of maximum brightness; exposure varied; Mn in* $CaSO_4$ *(1:500).*

With the fluorites and calcites it had been observed[3] that the activity imparted to the materials by x-rays was not permanently fixed but decayed slowly on standing like the effect of slow phosphorescence.

This study showed also an apparent increase in activity about half an hour after exposure to the rays. To examine the effect of decay with time we made a series of measurements of the brightness of the maximum for a specimen rayed for a certain length of time and heated always to the same temperature, allowing about ten minutes between each reading.

Fig. 5 shows the results obtained from Sample *B* (1 : 250) exposed to the rays for one hour and heated to a temperature of 120°C. The curve shows a brighter maximum 27 minutes after the exposure than immediately after the raying was stopped. The figure shows also the same effect at a higher temperature for both of the samples. The maximum here appears at about 50 minutes after exposure.

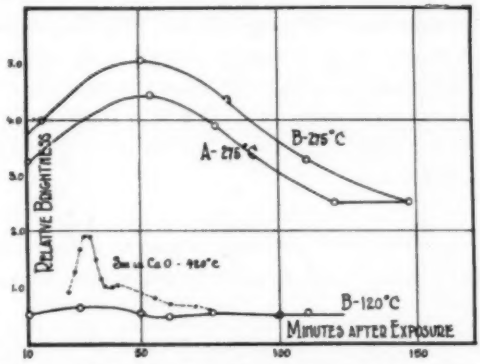

FIG. 5. *Curve of maximum brightness; time after exposure varied; Mn in $CaSO_4$; A = (1:500); B = (1:250); samarium in CaO (dotted line).*

The same experiment was made with CaO containing a small amount of samarium. The sample was rayed for 65 minutes, and the brightness of its yellow maximum at a temperature above 420° was examined as a function of the length of time after exposure. This, too, shows a maximum (dotted curve, Fig. 5) at about 30 minutes after the exposure ends. The steepness of the curve is probably due to the high temperature to which the substance was heated.

It would seem that this increase in activity is a characteristic of all thermoluminescent materials independent of the nature of the solvent or activator. It has been found in every one so far tested—(3) calcites, fluorites, chlorophane, Mn in $CaSO_4$ and Sm in CaO. A somewhat similar effect has been observed in photography.

Professor E. L. Nichols has told us of a paper presented at a Meeting of the American Philosophical Society sometime ago on the effect of variation of time between exposure and development on the intensity of the photographic image. It was shown that for some plates there was an increase in blackening if the plate was left for a few minutes after exposure. The experiment was repeated at Cornell University by Professor G. S. Moler with time intervals varying from a fraction of a second to 19 minutes. For the plate used (ordinary Seed 26) a distinct increase in intensity was found when development began 8 minutes after exposure. This could not be duplicated with all plates. It is not surprising to find the same effect in both cases, since both are examples of a change due to radiation.

The work of Vaillant[5] on the conductivity of phosphorescent CaS should also be noted here. If after a sufficiently long exposure to light from an incandescent lamp a sample of CaS is taken into a constant temperature dark room, conductivity *increases* rapidly, attaining after a few hours (9 hours) a maximum *much greater* than that corresponding to the excitation maximum and then decreases very slowly. Data are reproduced in Table 2.

TABLE 2.

Time after exposure Hours	Conductivity	Time after exposure Hours	Conductivity
0	137 (megohms)	18	46000 (megohms)
1	12700	22	45900
2	25600	48	34000
3	3620	66	13800
4	41600	90	4680
9	46000		

If the excitation is stopped before saturation is reached the conductivity increases in the dark and reaches a maximum slightly lower and more quickly reached than if the exposure had been continued. Vaillant has not developed a theory to explain this effect.

Fig. 6 shows the effect of lowering the temperature at which the specimens were exposed. In all previous measurements exposures were made at room temperature.

[5] M. P. Vaillant, Comptes Rendus, *171*, p. 713; 1920.
153, pp. 1141–1144; 1911.

A portion of Sample *B* was placed upon a thin copper block, which was used as a lid for an evaporating dish, filled with a mixture of ice and $CaCl_2$. The sample was then rayed for 30 minutes. No attempt was made to measure the exact temperature. At the end of one hour and forty minutes, when the maximum effect of time should be past, the effect of temperature upon the brightness of the maximum was determined.

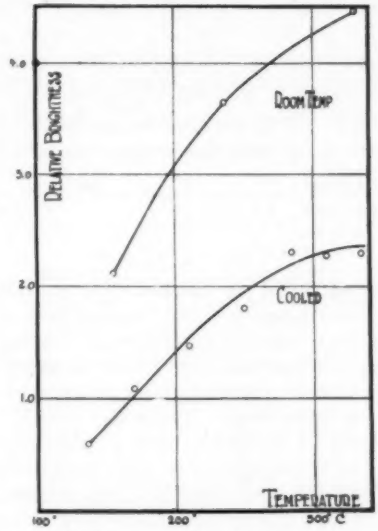

FIG. 6. *Curves of maximum brightness; temperature of exposure and temperature of observation varied.*

Another portion of the same specimen was rayed on the same copper block, in the same position, for 30 minutes, at room temperature, and allowed to rest for 100 minutes, the same as the previous sample. The effect of temperature on the brightness of maximum is shown in Curve 8. The specimen exposed at room temperature evidently stored a greater amount of energy than at a lower temperature.

SUMMARY

1. Traces of manganese in solid solution in $CaSO_4$ make the substance susceptible to the action of x-rays.

2. The thermoluminescence is green in color (4800–5600 A).

3. The decay of luminescence at 120° shows a curve of the persistent type (Fig. 1).

4. The maximum brightness for a given substance after exposure shows a straight line relation with temperature (Fig. 2.)

5. Saturation is reached for low temperatures (260°) within an hour exposure to the rays (Figs. 3 and 4).

6. Synthetic thermophosphors show an increase in activity on standing a few minutes after exposure (Fig. 5).

7. Decreasing slightly the temperature at which a specimen of Mn in $CaSO_4$ was exposed caused an apparent decrease in energy stored.

The authors wish to express their appreciation of the courtesy shown them by the Department of Physics of Cornell University during the course of this research. They are especially grateful to Professor E. L. Nichols through whose interest the work was made possible.

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Susceptibilities of Solid or Liquid Na, K, Rb, Cs at various temperatures.—Determinations by the method of measuring the force exerted by a non-uniform magnetic field upon the sample, the evaluation of the actual field and field upon the sample, the evaluation of the actual field and field gradient being avoided by making standardizing measurements upon water (for which $-0.72 \cdot 10^{-6}$ is taken as the susceptibility, and $23.8 \cdot 10^{-6}$ as that of air). As the temperature is raised from 0°C the susceptibility of each metal increases slowly and then more rapidly up to the melting-point, whereupon it drops off rather suddenly, then remains nearly constant over a certain range and starts gradually upward once more. As Na, K, and Rb are paramagnetic and Cs diamagnetic, it is interesting that their four curves resemble one another very closely, notably in the absolute magnitude of the decrease near the melting-point; this decrease, being algebraic, signifies an actual increase in the numerical value of the (negative) susceptibility of Cs. The actual data are not shown either on the graph or in tables, which is regrettable.—[W. Sucksmith (Bristol); Phil. Mag., (7), *2*, pp. 21–29; 1926.]

KARL K. DARROW.

ELEVENTH ANNUAL MEETING OF THE OPTICAL SOCIETY OF AMERICA

MINUTES

The eleventh annual meeting of the Optical Society of America was held at the Franklin Institute in Philadelphia on Thursday, Friday and Saturday, Oct. 21, 22, 23, 1926. There were about 60 members in attendance at this meeting. The sessions were held in the century old lecture room of the Franklin Institute and were opened on Thursday morning with a cordial welcome by Dr. McClenahan on behalf of the Franklin Institute.

An address was given on Friday afternoon by Professor E. N. Harvey of Princeton University on "The Production of Light by Living Organisms" which aroused considerable interest and discussion. After the banquet, which was held at the Benjamin Franklin Hotel on Friday evening, Professor John Miller of Swarthmore College gave an address on "The Total Solar Eclipse of 1926." The talk was illustrated with many beautiful slides and was an interesting and delightful aftermath to the banquet.

At the business meeting on Friday morning, the Executive Council reported the following membership changes approved at its annual meeting, held October 21:

New Associate Members since the Annual Meeting of October, 1925

F. Bedell	J. H. Ellis	A. S. King	P. A. Ross
F. L. Bishop	G. Failla	C. M. Kilby	E. W. Skinner
D. W. Bronk	A. T. Fant	G. G. Kretchmar	C. W. Smith
L. J. Boardman	L. V. Foster	L. Logan	C. Snow
D. E. Branson	P. F. Gaehr	B. Long	T. S. Taylor
R. E. Burroughs	L. Gilchrist	B. MacNutt	E. W. Tschudi
G. A. Chambers	S. Harris	W. A. Marrison	C. T. Ulrey
H. R. Childs	J. R. Harrison	T. Meloy	J. H. Van Vleck
H. Clark	P. Hodge	W. R. Miles	A. B. Wootem
C. D. Cooksey	L. L. Holladay	R. J. Piersol	C. G. F. Zobel
F. L. Cooper	F. F. Householder	N. P. Raschevsky	
T. M. Dahm	W. J. Humphreys	F. F. Renwick	
W. F. Davidson	C. E. Irion	C. W. Rice	
L. E. Dodd	A. Joffe	J. K. Robertson	
N. E. Dorsey	J. C. Jensen	T. W. Rolph	
M. Dresbach	I. T. Jones	G. L. Rose	

Transfers from Associate Membership to Regular Membership, by Vote of the Executive Council:

F. Bedell	W. J. Humphreys
D. W. Bronk	D. B. Judd
H. Clark	A. S. King
C. D. Cooksey	B. MacNutt
L. E. Dodd	W. R. Miles
N. E. Dorsey	R. J. Piersol
M. Dresbach	N. Raschevsky
G. Failla	F. F. Renwick
L. V. Foster	J. K. Robertson
P. F. Gaehr	P. A. Ross
L. Gilchrist	C. Snow
G. R. Harrison	J. A. Spengler
P. Hodge	T. S. Taylor
L. L. Holladay	J. H. Van Vleck

Mr. Adolph Lomb was reelected Treasurer to succeed himself, for a five-year term beginning January 1, 1927.

In making the nomination of Mr. Lomb, Professor F. K. Richtmyer pointed out the great debt of the Society to Mr. Lomb for his loyal and unselfish support since the inception of the Society and voiced the deep appreciation of the Society for his unflagging interest, wise council and substantial support during all the years of the Society's existence.

Professor Richtmyer on behalf of the Board of Editors of the JOURNAL announced that the practice of supplying free reprints to contributors of the JOURNAL would, after an early date, be discontinued.

President Forsythe announced the time and place of the next annual meeting as October, 1927, at Schenectady, N. Y., accepting the invitation of Drs. Whitney and Dushman of the General Electric Company.

The advisability of a joint mid-winter meeting with the American Physical Society was discussed and left to the discretion of the President.

The appended papers were presented during the several sessions.

(Signed) CHARLES C. BIDWELL
Secretary

Contributed Papers

William G. Exton, M.D. Laboratory of The Prudential Insurance Company of America

A NEW METHOD OF COLORIMETRY.

Because so many reactions give characteristic colors chemists find color measurements increasingly useful, especially in medical and biochemical work with their limitations as to time and sample. Current practice consists in treating at the same time and in the same way as the unknown, a solution of known concentration which serves as a comparison standard when compared or matched in an instrument of the Duboscq type. This technique is practicable and very useful but has inherent limitations and disadvantages connected with the repeated preparation of comparison standards and their manipulation. These have lately been emphasized by numerous more or less ill-advised efforts to provide permanent standards.

The new method removes all such difficulties by completely eliminating comparison standards. Besides other advantages such as increased range and avoidance of interfering colors, it works with volumes minute enough for micro methods. Very satisfactory results have been had with the colors of different sugar tests on blood and urine with the phenolsulfonophthalein test in the presence of interfering colors of blood and urine, in the estimation of blood hemoglobin and in the determination, without the use of buffers, of the pH of blood.

Since the common logarithm of the reciprocal transmission (color density) is proportional to the depth of the solution measured, its rate of change with depth equals the density at at unit depth, i. e., sensitiveness increases in direct proportion to density. The new method measures color at its greatest density or the frequency most absorbed by isolating the absorption band with a color filter and measuring its intensity by depth or by neutral wedge. Three filters, a red, green, and blue have answered for measuring the concentration of all of the different colors of solutions so far experimented with.

Provisions for the rapid and easy application of the absorption band method have been incorporated in the scopometer which was shown the Society in 1924 for measuring turbidity. In this way the method is practicable with both photometric and extinction criteria. Because the absorption band method is more sensitive, an extinction criterion actually becomes more precise than the photometric comparisons made with the Duboscq as ordinarily used, but with sufficient light and proper filter the Duboscq is improved by combination with the absorption band method.

The present paper will appear in full in J.O.S.A. & R.S.I.

R. Davis and K. S. Gibson **Bureau of Standards**

REPRODUCIBLE LIQUID FILTERS FOR THE PRODUCTION OF "WHITE LIGHT".

Both for photographic sensitometry and for colorimetry, filters for converting the color of incandescent illuminants (2360°–3000°K) to "white light" (5000°K or mean sunlight) are proving more and more desirable. Such filters, to be of the greatest general value, should be reproducible, permanent, of practicable dimensions, and composed of materials readily obtainable.

The glass and gelatine filters on the market are not considered precisely reproducible nor do they give a resulting energy distribution as close to the ideal as it is possible to obtain with liquid filters. The quartz-nicol combinations are small and relatively expensive.

Previous workers with liquid filters have used a double glass cell, one chamber of which contains an aqueous solution of copper sulphate with or without cobalt sulphate, the other an ammoniacal solution of copper sulphate.

The authors are investigating:

1. The use of a double cell, one part containing an acidulated aqueous solution of copper sulphate and cobalt sulphate, the other an ammoniacal solution of copper sulphate.

2. A similar cell containing, respectively, an acidulated aqueous solution of copper sulphate and cobalt sulphate, and a pyridine solution of copper sulphate to which mannite is added as a preservative.

A spectral range from 350 to 720 mμ is being studied, and filters are being devised, by altering the concentrations of the components, for converting the color of sources having color temperatures between 2360° and 3000°K to the color of sunlight and 5000°K. The work may be extended to include other "white" standards.

Very encouraging results have already been obtained, particularly in the conversion of acetylene to sunlight color. The questions of permanence and change with temperature are being studied. Integral light transmissions on the basis of standard visibility data will also be computed, so that if the candle power of the source alone is known that of the source and filter combination may be readily obtained.

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Report of O.S.A. Committee on the Unit of Photographic Intensity, J.O.S.A. & R.S.I., *12*, pp. 570–575; June, 1926.

K. S. Gibson **Bureau of Standards**

A PROPOSED METHOD FOR THE MEASUREMENT OF THE RELATIVE VISIBILITY FUNCTION.

Consider a two-part photometric field, one part illuminated by heterogeneous light L_s of standard brightness for heterochromatic photometry, the other part by a mixture of homogeneous light L_λ and heterogeneous light L_m of the same color as L_s. Let the brightness of L_m be variable in a known manner, so that $L_m + L_\lambda$ may be matched in brightness with L_s and L_λ computed. Furthermore, let the color of L_s and L_m be such as to give a good color match with L_λ at the wave length of maximum luminosity. This condition may easily be obtained by filters of high purity.

Under these conditions, as luminosity measurements are made at wave lengths differing more and more from the wave length of maximum L_λ, the tendency for the hue difference in the two parts of the field to increase is more or less nullified by the increasing proportion of L_m to L_λ. When, towards either end of the spectrum, L_λ/L_s would otherwise become less than 10 or 20 per cent, L_λ should be increased several fold and the filters coloring L_s and L_m changed accordingly, still keeping L_s at standard brightness level.

If the dividing line of the field is the edge of a polished flicker disk which may be rotated in the usual way for flicker photometry, a means is provided for comparing visibilities by the so-called equality-of-brightness and flicker criteria, under strictly identical experimental conditions, avoiding the tediousness, lack of independence, and variable luminosity of the step-by-step method and the large color differences otherwise necessary.

Advantages of the proposed method thus are:

(1) Luminosity measurements at constant (standard) brightness level.

(2) Greater spectral range at standard brightness level than otherwise possible.

(3) Lower spectrum current, with increased constancy of energy calibration, than otherwise possible.

(4) Much less color difference than when measuring visibility by direct equality-of-brightness photometry. (Also true by flicker photometry but of less importance.)

(5) Undesirable features of step-by-step method eliminated.

(6) Comparison of visibilities by flicker and equality-of-brightness photometry under identical experimental conditions facilitated.

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Irwin G. Priest and K. S. Gibson **Bureau of Standards & Munsell Research Laboratory**

APPARATUS FOR THE DETERMINATION OF THE VISIBILITY OF ENERGY AND THE FUNDAMENTAL SCALES OF VISUAL PSYCHOPHYSICS

The immediate purpose of the present paper is to introduce Dr. Tyndall's paper by describing the apparatus which he used.

This apparatus has been developed from that exhibited at the Washington meeting of the Optical Society, 1922 (J. O. S. A., 7, pp. 99–100). It will be described in its present state and plans for further improvements will be outlined. The cardinal features of the apparatus remain as previously described in the reference just given, but numerous improvements in details have been effected. As now planned, it will provide for the determination of:

1. The visibility of energy

(a) by the "step-by-step" method, or

(b) by comparing the spectral brightness with a constant comparison source, using either equality-of-brightness by juxtaposition or the flicker criterion, or

(c) by a modification of these latter methods as proposed by Gibson, elsewhere in this program.

2. The least perceptible difference in brightness as a function of brightness, wave length, field size, and other incidental variables.

3. The least perceptible difference in wave length *which can not be eliminated by adjustment of purity, or brightness*, as a function of wave length, purity, brightness, etc.

4. The least perceptible difference in purity as a function of wave length, purity, etc.

An outstanding feature of the apparatus is the provision for determining visibility by the different recognized methods *with the same apparatus*. A much more direct comparison of methods will thus be possible. *So far as a comparison of methods is concerned, no measurements of energy are involved.*

In an extensive campaign of determining the visual sensibilities, the advantage of one standard apparatus will be apparent to all who are acquainted with the elaborate calibrations and instrumental corrections incident to such work.

The work carried out by Tyndall has demonstrated the utility of this apparatus to a certain extent. It is intended to maintain the apparatus at the Bureau of Standards for a long period so that other investigations as indicated above, may be expedited.

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E. P. T. Tyndall **Munsell Research Laboratory and Bureau of Standards**

SENSIBILITY TO WAVE LENGTH DIFFERENCE AS A FUNCTION OF PURITY.

Using the apparatus designed by Priest and Gibson, the writer has determined sensibility to wave length difference for his right eye:–

(1) For stimuli of unit purity (spectral light) from 450 to 645 mμ.

(2) For stimuli consisting of artificial noon sunlight plus homogeneous light of some selected wave length, the wave lengths being 455, 470, 481.5, 493, 530, 580, 635mμ, and the purities ranging from unity to a few per cent.

(3) For stimuli consisting of homogeneous light of wave length 455 plus some one of the heterogeneous stimuli specified as follows: (a) equal energy, (b) color temperature 2570°K, (c) color temperature over 24000°K.

(4) For a stimulus consisting of homogeneous light of wave length 530 mμ plus heterogeneous light of color temperature over 24000°K.

The results of 1 are concordant with previous determinations by others. The least perceptible difference (L.P.D.) in wave length for 2 shows, for wave lengths 635, 580, 530, and 493 mμ, at first a slow and then, near zero purity, a rapid increase as purity is decreased. For wave length 455 mμ with decreasing purity, the L.P.D. at first increases and then decreases to a pronounced minimum at about fifteen per cent purity, increasing rapidly beyond this. Wave lengths 470, and 481.5 mμ show a similar but less marked effect.

The experiments noted under 3 and 4 are undertaken in order to study the effect of the spectral distribution of the heterogeneous stimulus in modifying the peculiar results just described for wave lengths less than 482 mμ. It is shown that the form of the curve showing L.P.D. as a function of purity depends upon the spectral distribution of the heterogeneous stimulus.

Two hypotheses are proposed to account for the peculiar results for short wave lengths and a possible criterion for true neutrality of the heterogeneous stimulus is suggested.

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I. G. Priest and D. B. Judd **Bureau of Standards and Munsell Research Laboratory**

SENSIBILITY TO WAVELENGTH DIFFERENCE AND THE PRECISION OF MEASUREMENT OF DOMINANT WAVELENGTH FOR YELLOW COLORS OF HIGH SATURATION.

Our purpose is to give more definite information than heretofore available on sensibility to wavelength difference, and the *precision* of measurements of dominant wavelength. The "limen" is *not* a discrete quantity. Consider a symmetrically divided field each half illuminated by the same wavelength and then let the wavelength in one half be changed. For small but finite changes there is *no* change in color. For large differences, there arises a hue difference which is *beyond doubt*. Intermediate differences are "perceptible" in the sense that the observer is *inclined* in the correct direction but is *not certain* a difference exists. Thus, the "limen" is amenable to a probability analysis.

With apparatus already described[1] we have determined:—

(1) The "greatest imperceptible difference" (GID).

(2) The "least difference perceptible *with certainty*" (LPD).

(3) The prob. errors of a single setting for: GID, (r′); LPD, (r″); **median settings** in which it is attempted to set the mean between "just too long" and "just too short", (r‴). To determine either GID or LPD, the observer makes alternate wavelength settings (with brilliance and saturation matched) on each side of "match". The GID or LPD is taken as ½ the interval.

MEAN RESULTS (from hundreds of observations) for normal trichromats; λ = 575 mμ; purity = 0.9; 2° circular matching field, divided on vertical diam., 3 to 4 millilamberts; 20° surrounding field, ½ millilambert, artificial sunlight; diam. artificial pupil = 3mm.

Observer	GID	LPD	r′	r″	r‴	GID/r‴	LPD/r‴	LPD/GID
Priest	0.13mμ	0.61mμ	0.12mμ	0.14mμ	0.15mμ	0.9	4.1	4.7
Judd	.24	1.13	.10	.16	.15	1.6	7.5	4.7
Gibson	.18	.70	.11	.16	.12	1.5	5.8	3.9
Tyndall	.28	.71	.12	.12	.20	1.4	3.6	2.5
Skinner	.18	.71	.09	.15	.12	1.5	5.9	3.9
Rudnick	.19	.62	.10	.20	.10	1.9	6.2	3.3
Mean	.20	.75	.11	.15	.14	1.4	5.4	3.8
	From probability analysis					0.8	3.1	4.1

Preliminary determinations by the "method of answers"[2] indicate:—(Tyndall) GID = 0.2 mμ; LPD = 0.6mμ; (Judd) LPD = 0.5 mμ. Tyndall's LPD with different apparatus (brilliance adjusted, purity constant)[3] is 0.53 mμ. Experiments over a period of two months indicate that the LPD for a given observer may vary by a factor of 2.

The values of LPD given above are notably smaller than found by Steindler[4], Jones,[5] and others. They are in substantial agreement with the findings of Rayleigh[6] and Laurens and Hamilton.[7] The above probable errors (r‴) of a single median setting are slightly less than like values computed from Koenig and Dieterici:[8]—Koenig, 0.19 and Dieterici, 0.23 mμ.

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7 Laurens & Hamilton: Am. Jo. Physiol. *65*, pp. 547–568.
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Irwin G. Priest **Bureau of Standards**

AN EXPERIMENT ON COLOR DISCRIMINATION UNDER COMMONPLACE CONDITIONS.

Available data on sensibility to difference in wavelength pertain to the very special conditions of instrumental observation. From the point of view of color discrimination in ordinary experience, such conditions are quite abnormal. I have attempted to obtain, in a particular case an indication of the sensibility under more usual conditions.

The experiment relates to the discrimination of the colors of two yellow glasses having nearly the same spectral transmission, as follows:

Wavelength		380–450	460	480	500	520	540	560	580	600	620	640	660	680	700	720mμ
T	Glass A	0.000	0.003	0.081	0.313	0.540	0.682	0.738	0.735	0.698	0.645	0.602	0.590	0.611	0.629	0.678
	Glass B	.000	.001	.067	.285	.518	.669	.730	.725	.680	.613	.561	.547	.577	.590	.647

Colorimetric characteristics for average noon sun (Abbot-Priest) have been computed as follows:

	A	B
Integral transmission (Gibson-Tyndall recommended V)	0.632	0.616
Dominant wavelength (O.S.A. Colorim. Com. basis)	576.0	575.8
Purity (O.S.A. Colorim. Com. basis)	0.931	0.936

That this *difference* in dominant wavelength is 0.2 mμ has been verified by careful systematic measurements by five trained observers, and by independent computation on the basis of revised values of the excitations.

These glasses were mounted side by side with their edges in contact over a circular hole, 18 mm in diameter, near the center of a piece of gray cardboard (about 20 x 27 cm) so that the two halves of the hole were covered respectively by the two glasses. The observer held the card about 30 to 40 cm from his eye and looked thru the glasses at a white paper illuminated by daylight. He was thus comparing the colors in a symmetrical two part circular field subtending about 3°. Seventeen observers (normal trichromats) attempted to report the color difference in terms of hue, saturation and brilliance. All showed hesitancy in deciding, and considered the difference (if existent) to be vanishingly small. Several thought the two glasses *might* be identical. However, decisions were finally made as follows:

	For Hue	For Saturation	For Brilliance
Number of observers in accord with objective difference	13	6	10
Number of observers contrary to objective difference	1	8	2
Number of observers quite unable to decide	3	3	5

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Mabel K. Slattery **Cornell University**

(Introduced by F. K. Richtmyer)

IS THE ABSORPTION OF LIGHT BY SODIUM VAPOR AFFECTED BY THE PRESENCE OF A MAGNETIC FIELD?

The extension of the quantum theory, by Sommerfield and others, to the problem of "space quantization" predicts that, in the presence of a magnetic field, the electron orbits are oriented only in certain directions with respect to the direction of the field, these directions being determined by the total quantum number of the orbit. Thus the orbit of the valence electron of sodium (vapor) in a magnetic field should assume such a direction that the cosine of the angle between the field and the normal to the plane of the orbit should be restricted to the values $+1$ or -1. The experiment of Gerlach and Stern seems to confirm this prediction.

Since, on the quantum theory, absorption of light involves a change of orbit, it seems reasonable to assume that the probability of any interorbital transition should be a function of the angle between the magnetic axis of the atom (when in the magnetic field) and some directional characteristic of the incident quantum—say the electric or magnetic vector. Experimentally, one might expect a change in absorption with a change of angle between the plane of polarization and the direction of the magnetic field.

Polarized light from a sodium flame was passed through a glass tube 6 cm long containing sodium vapor at 280°C, and placed in a uniform magnetic field, the field being perpendicular to the path of the light. No change of absorption was observed for a field of a few gauss. But with fields of 1000 gauss, there was a slight indication of an *increase* in absorption when the magnetic vector of the polarized light was *perpendicular* to the field.

Although the effect was consistently reproducible, the great difference between the width of the emission and the absorption lines and the limited accuracy of photometric measurements at low intensities combine to make the result somewhat uncertain. The experiment should be repeated under conditions permitting higher precision.

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Richard M. Bozorth and F. E. Haworth **Bell Telephone Labs., Inc., N. Y. C.**

THE CRYSTAL STRUCTURE OF MAGNESIUM PLATINOCYANIDE HEPTAHYDRATE.

The crystal structure of $MgPt(CN)_4 \cdot 7\ H_2O$ has been determined with the aid of spectral and Laue photographs in order to explain if possible some of the peculiar optical properties which these tetragonal crystals exhibit. It is believed that the dichroic polarized fluorescence (rays polarized in the direction of the tetragonal axis are yellow, those polarized perpendicular to the axis are red) is intimately related to the arrangement of the heavy Pt and Mg atoms, which lie in rows parallel to the tetragonal axis. In these rows, Mg atoms alternate with Pt atoms, and the distance between any two adjacent atom-centers is 1.57A. The shortest distance between rows, however, is 10.3A, 6.6 times the distance between atoms in the same row. Therefore vibrations of the metal atoms probably encounter much greater resistances in the axial direction than in directions perpendicular thereto. Having determined the distance between two positive ions when "in contact" according to W. L. Bragg's hypothesis of atomic radii, and knowing already the distances between many pairs of negative ions, and also between positive and negative ions, the authors distinguish between two commonly used sets of radii, one of which assigns to K^+, e.g., a radius about twice that of Cl^-, the other of which assigns to K^+ a radius not greatly different from that of Cl^-. The first set was proposed by W. L. Bragg in 1920; the second set, consistent with the distance between Mg^{++} and Pt^{++} in $Mg\,Pt\,(CN)_4 \cdot 7\ H_2O$, was proposed by J. A. Wasastjerna, is now adhered to by W. L. Bragg, and has values very close to those proposed by W. P. Davey.

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11. C. C. Kiess and Harriet K. Kiess **U. S. Bureau of Standards**

SPECTRAL REGULARITIES FOR Zr II AND Zr III.

The spark spectrum of Zr has been measured at the Bureau of Standards from 2100A in the ultra-violet to 6300A in the red. For many of these lines new measurements of the Zeeman effects have been derived from recent observations made by the late Prof. B. E. Moore of the University of Nebraska. Nearly 50% of these lines, which includes practically all the lines of intensity 3 or greater have been classified as members of the doublet and quartet systems of Zr II, and of the singlet and triplet systems of Zr III. The normal state of Zr II is a^4F. Metastable states of Zr^+ are represented by b^4F, c^4F, a^4P, b^4P, a^2D, b^2D, c^2D, a^2P, a^2F, a^3G, b^3G, and a^5H. Above these come triads of S, P, D, F, G, and H, terms which combine with the low terms according to the well-known rules. The normal state of Zr III is probably ^3F. A triad of ^3D, $^3F'$, ^3G, and $^1F'$ terms have been found. Among these terms (and also those of Zr I, which have been established by the authors) are several which are series-forming. These lead to a value of 6.5 volts for the ionization potential of the Zr atom.

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W. F. Meggers **Bureau of Standards**

STRUCTURE OF THE La II SPECTRUM.

The first regularities in the spark spectrum of lanthanum were discovered by Popow (1) and a number of new levels were recently identified by Goudsmit (2) from the Zeeman-effect observations of Rybar (3). With the aid of additional data on Zeeman effects observed by the late Prof. B. E. Moore, and a comprehensive temperature classification of lanthanum

lines by Dr. A. S. King and Miss Carter, it has been possible to extend the analysis and classify 180 lines with S, P, D, F, and G terms in the singlet and P, D, F terms in the triplet systems.

Like Sc II (4) and Yt II, (5) the lines of ionized La appear very prominently in the solar spectrum and it is of interest to compare the structures of these three spectra. The analysis shows that the three spectra are very similar but La II has some distinctive features. The lowest energy in Sc II and Yt II is represented by $^3D_1$ while in La II it is $^3F_2$. In addition to the terms known for Sc II and Yt II, a set of triplet P, D, F, and G terms is found for La II. This indicates that electron configurations involving *f*-type electrons are prominent; they are probably responsible for the rare-earth like character of lanthanum.

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The present paper will appear in full in J.O.S.A. & R.S.I.

13. William Mayo Venable **Blaw-Knox Company**

CLASSIFICATION OF LINES OF THE SECONDARY SPECTRUM OF HYDROGEN.

In the "Secondary" spectrum of Hydrogen, over 1100 lines have been measured, of which less than 70 have been hitherto classified into groups, which are:—

(a) Three related series of seven or more terms each, discovered by Richardson and Tanoka.

(b) Five related series of five terms each, known as the First Fulcher Band.

(c) Four related series of four terms each, known as the Second Fulcher Band.

These groups are shown to be sub-divisions of three larger groups, and several hundred additional lines belonging to the large groups have been classified. The group containing the Second Fulcher Band contains altogether 123 lines, all of which are given.

A physical explanation of the origin of these lines is offered.

Arthur L. Schoen **Research Laboratory, Eastman Kodak Co.**

A PHOTOGRAPHIC METHOD OF SPECTROPHOTOMETRY IN THE RED AND INFRARED.

Following the discovery of Neocyanine, a new photographic sensitizing dye for the red and infrared, photographic spectrophotometry in this region of the spectrum has been simplified considerably. Spectrophotometric apparatus consisting of a prism spectrograph, polarization photometer, and small "high intensity arc lamp" will be described. With this equipment the absorption curves for the Wratten light filters and several photographic sensitizing dyes have been measured from 500 to 900 mμ.

The present paper will appear in full in J.O.S.A. & R.S.I.

Lewis E. Jewell **Research Laboratory, Eastman Kodak**

AN IMPROVED TYPE OF ILLUMINATION FOR USE IN METALLOGRAPHIC AND MINEROLOGICAL MICROSCOPY.

The paper describes an illuminator adapted for certain kinds of microscopy. The most novel features are a half prolate ellipsoidal hole in a stellite mirror inclined at an angle of 45° to the microscope axis, and a "nose piece" iris diaphragm. The light coming from one side is reflected by the mirror down through one-half of the objective (except the central portions). The result is specular reflection from polished plane surfaces of the object which are perpendicular to the microscopic axis. This light passes back through the outer portions of the other half of the objective. This light irregularly or diffusely reflected from the object passes through the objective, and the hole in the mirror, as well as the unobstructed half of

the objective and gives a relief effect. The iris diaphragm limits the intensity of the specular reflection to any desired intensity. The nose piece diaphragm is also very useful where transparent objects are examined. The advantage of a wide-angled beam of light illuminating the structural detail of the object is retained. Illustrations show detailed plans of the illuminator and photomicrographs are given.

The present paper will appear in full in J.O.S.A. & R.S.I.

Arthur C. Hardy and Frederick W. Cunningham **Massachusetts Institute of Technology**

A METHOD OF CONTROLLING THE INTENSITY OF A SMALL LAMP WITHOUT THE USE OF ELECTRIC MEASURING INSTRUMENTS.

A simple Wheatstone bridge method of controlling the luminous intensity of a small lamp has been devised. This method does not require a galvanometer and should therefore be useful in small portable photometers or exposure meters. Under favorable conditions, the average deviation in intensity of a single setting is less than 2%. A model will be exhibited.

H. J. McNicholas **Johns Hopkins University and Bureau of Standards**

ON THE USE OF THE INTEGRATING SPHERE IN REFLECTOMETRY.

The photometric integrating sphere has been applied in various ways to the measurement of the ratio of total reflected to total incident light for various diffuse reflecting media. The methods of use proposed by Sharp and Little[1] and by Karrer[2] are tested in this work, using a set of samples covering a wide range of glossiness and absolute reflection. In this test, the brightness of the sample, under nearly completely diffused illumination from a hemispherical source, is observed for various angles of view from the normal to the surface, and the total reflected light flux computed from these data. The total illumination on the sample is likewise computed from the measured brightness distribution over the hemispherical source.

The brightness of glossy samples is found to increase considerably with increasing angle of view from the normal to the surface, confirming the results of the computations of Walsh[3] and his prediction of large errors in the performance of the sphere.

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W. B. Rayton **Bausch and Lomb Optical Company**

AN IMPROVED POLARIZATION PHOTOMETER.

Polarization photometers of the Martens type now available are characterized by the fact that it is impossible to graduate them with an accurate density or transmission scale. This is due to the fact that when they are adjusted so that the two fields extinguish at 0° and 90° respectively the match point does not fall exactly at 45°. An instrument will be described in which this difficulty has been eliminated permitting the great advantage to be obtained of making it direct reading.

F. E. Wright **Geophysical Laboratory**

A NEW POLARIZATION PHOTOMETER EYEPIECE.

This device was constructed to serve primarily as an eyepiece on an astronomical telescope for use especially in a study of the amount of polarized light reflected by different parts of the moon's surface under different angles of incident illumination. For this purpose it is essential that the image of the object be viewed at the time the photometric readings are taken. The device consists of a Wollaston prism to one end of which is cemented a negative lens and to the opposite end a positive lens. The two pencils of converging rays from the Wollaston prism pass through a bi-prism, mounted so as to be movable along the telescope

axis, and thence to a second bi-prism in the image plane of a low power ocular, in front of the lens of which is mounted a rotatable analyzer. On placing the eye at the small exit pupil of the instrument, two images of the object under study are seen, one on each side of the photometric field. The first bi-prism is moved until the images of any specified point are in juxtaposition; the analyzer is then rotated until the two images are equally illuminated, and from the position of the analyzer the amount of polarized light present is computed. By removing the negative lens from the Wollaston prism the eyepiece is converted into a low power telescope suitable for studying sky polarization and allied phenomena.

Deane B. Judd **Cornell University**

APPARATUS FOR THE CONTROL OF STATIONARY LIGHT STIMULI

A rotary tachistoscope has been devised in which the episcotister and an electrically controlled, auxilliary shutter both fall close to the focal plane of the illuminating beam. This arrangement accomplishes accurate control of duration. Light from the source lamp passes (1) through a condensing lens system, (2) the shutter system, (3) through a series of diffusing and absorbing screens and illuminates a lantern slide. A same-size image of this slide is projected on a ground-glass screen from behind. This image serves as stimulus for the observer in front of the screen.

The principal advantages of the apparatus are:

(1) A light pulse is produced whose duration is continuously variable between 0.005 and 2.0 seconds. The rise from zero to maximum intensity and the subsequent cut-off of this pulse is so rapid as to be negligible even for the shortest durations.

(2) The intensity of the light stimulus is continuously variable from 0.001 up to 500 ml.

(3) The intensity of the surrounding field is continuously variable from 0.0001 up to 0.5 ml.

(4) A sharp image of any object that can be placed on a lantern slide may be projected as a monocular or binocular stimulus.

The present paper will appear in full in The American Journal of Psychology (January, 1927).

Deane B. Judd **Cornell University**

A QUANTITATIVE INVESTIGATION OF THE PURKINJE AFTERIMAGE

The response to a momentary retinal illumination is usually described as a series of images. These images vary widely in number and character with the attributes of the stimulus (intensity, duration, quality) and equally as widely with attendant experimental conditions (surrounding field attributes, retinal region stimulated, state of adaptation of the observing eye to light, etc.). The largest number of images or phases that have been identified in the response to a momentary retinal illumination of moderate intensity is eight, —four bright (positive) phases and four dark (negative) phases. The third bright phase (i. e. the third positive image or second positive after-image) has been designated as the Purkinje afterimage because of its discovery by Purkinje in 1819.

The attributes of the Purkinje afterimage, as described in the literature and checked in the present work, are as follows:

(1) It appears brightest about one-half second after the end of the stimulus.

(2) It is preceded and followed by a dark (negative) phase.

(3) Its hue is characteristically complementary to that of the primary image *when that image possesses a hue.* The Purkinje phase following a white primary image is bright and nearly white.

In the present work a determination has been made of the following quantities:

(1) The smallest stimulus brightness (in photons) which elicits a noticeable Purkinje after image as a function of the duration of the stimulus,

(2) Liminal brightness (same as in 1) as a function of the adaptation of the observing eye to darkness,

(3) The smallest visual angle by which two lines in the stimulus (width of line equal to their separation) must be separated in order to be perceived as distinct in the Purkinje after-image, (This angle was determined as a function both of stimulus duration and of surrounding field intensity.)

(4) The stimulus brightness at which the complementary character of the Purkinje phase was best aroused. This was done for four stimuli of widely different dominant wavelengths.

These results, together with the findings of most other workers, seem to be explicable on the basis of the assumption that nerve activity causes, or is accompanied by, the emission of light of low intensity.

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The present paper will appear in full in The American Journal of Psychology (April, 1927).

M. Katherine Frehafer **Goucher College**

PRELIMINARY NOTE ON AFTER-IMAGES FROM STIMULI OF LOW SATURATION AND SHORT DURATION.

Of the three positive after-images usually observed from a stimulus of short duration (.13 second), there is one that is, under the proper conditions, almost complementary in hue to the stimulus. An attempt was made to study the characteristics of this image (the Purkinje, so called) for white and nearly white stimuli. It was thought possible that a white Purkinje image might be observed.

Data were obtained from 10 observers, of whom 6 had had some previous experience in similar work. The circular stimulus used (light from a 1,000 watt lamp, passed through a filter, diffused, and focussed on a ground glass screen) was not uniformly illuminated, but was brighter in the center and fell off to ½ this value at the edge. From such a graded stimulus both the first image and the Purkinje can be viewed simultaneously, a condition that aids the observer in recognizing the Purkinje image and in determining its hue, by comparison with the other.

As a result of this preliminary work, the following facts have been noted. 1. Under the conditions used, the hue characteristics of the after-images showed enormous variation, embracing all the spectrum hues, plus purple. An observer who on first trial reported white images, on subsequent trials became more and more sensitive to the presence of hue. 2. All observers at some time reported blue images, usually of low saturation. There were a few reports of unsaturated yellow from unsaturated blue stimuli; but blue images predominated. Some observers distinguish lavender, purple or violet images, both in place of and in addition to the blue. 3. Although the blue image changes in character as one passes from a yellow to a white to a blue stimulus, it does not seem to become unmistakably white. This method cannot be used, apparently, to determine the stimulus that will evoke the white sensation, unless subsequent work with stimuli of different types yields an image of more distinctive character than any so far obtained.

Bibliography:
See references to previous paper by D. B. Judd.

Charles Sheard **Mayo Clinic and Mayo Foundation**

THE SPECTROPHOTOMETRIC ANALYSIS OF THE COLOR OF THE SKIN.

The color of the skin is dependent upon a variety of causes which may in a general way be grouped as due to (a) pigmentation, or melanin, (b) character, amount and distribution of the blood in the capillary bed of the skin. By means of spectrophotometric data obtained by reflection from the surface of the skin and by subsequent analysis into excitation color curves it is possible to draw conclusions of importance in both normal and pathologic conditions. It will be shown that: (1) spectral analyses show that there is a very close agreement in the values of the dominant wavelength, purity and percentages of red, green and violet in normal

blondes and brunettes, mulattoes and in such conditions as Addison's disease; (2) in polycythemia, the congestive stage of Raynaud's disease and allied conditions, there are marked departures from normal color curves; (3) cyanosis is noticeable in certain diseases; analysis shows that there is a marked reduction in the summated values of the reds and greens in patients with these conditions as compared with normal persons.

The present paper will appear in full in Archives of Internal Medicine.

Charles Sheard **Mayo Clinic and Mayo Foundation**

SPECTROPHOTOMETRIC STUDIES OF BILE PIGMENT.

In this paper the results of recent experimentation, in which spectrophotometry has been employed as the method of examination, will be presented. These investigations have to do with: (1) the effects of fading and slight degrees of turbidity and hemolysis on the spectrophotometric determination of bilirubin in blood plasma or serum, and other details of technic; (2) the proof of the assertions that (a) bilirubin is formed in the spleen and the bone marrow, (b) that bilirubin is formed from hemoglobin and (c) that hematin appears as an intermediate product in the formation of bilirubin from hemoglobin; (3) that the liver is a site of bilirubin formation. While bilirubin is made in both the spleen and liver, the amount is insignificant as compared with that made in the bone marrow. More bilirubin appears to be made in the spleen than in the liver. The paper will close with a presentation of a spectrophotometric analysis of blood serum in normal and pathological conditions.

Charles Sheard **Mayo Clinic and Mayo Foundation**

THE EFFECTS OF ULTRAVIOLET RADIATION UPON GROWTH AND DEVELOPMENT.

The results of a number of experiments will be presented and discussed regarding the influence of radiant energy and of ultraviolet radiation in particular on the periods of incubation, metabolism, growth and life of eggs (frogs, chickens and so forth) when treated and cared for under varying conditions, and upon the germination of seeds and growth of plants. The curves of germination of seeds and the curves of growth under selected filters with normal sunlight and again with ultraviolet radiation (from a Victor X-Ray Corporation mercury arc lamp) have demonstrated that the ultraviolet radiations are conducive to endogenous growth and development, hence to seed germination and root growth, but that the green and yellow portions of solar energy are most conducive to plant growth or exogenous development. Experiments will be described showing the effects of ultraviolet radiation upon hens' eggs, as affecting the periods of incubation and the resistance to disease evidently developed by pre-natal radiation.

Arthur C. Hardy **Massachusetts Institute of Technology**

THE OPTICAL SYSTEM OF THE OSCILLOGRAPH AND SIMILAR RECORDING INSTRUMENTS.

A study has been made of the optical system usually employed to record the deflection of a beam of light on a moving strip of film. Expressions have been derived for the exposure on film, the size of spot, and the deflection of the spot for a given rotation of a mirror in a system employing either spherical or cylindrical lenses. By the use of these, it is possible to calculate in advance the performance of any system and to insure sufficient illumination to make the trace visible upon development.

It is shown that the illumination is in all cases limited by the dimension of the mirror normal to its axis of rotation. The dimension of the mirror parallel to this axis affects the illumination only when sperical lenses are used throughout. The importance of using a small deflection together with a spot of corresponding size is demonstrated.

P. V. Wells **Laboratory of the Prudential Insurance Co. of America**

THE DILUTION LAW IN TURBIDITY MEASUREMENTS.

Tyndallmeters, nephelometers, and turbidimeters are generally used to measure the mass of a precipitate formed under conditions which assure reproducible sizes of particle. The turbidity readings are assumed to be proportional to concentration and depth, but this simple dilution law is followed only over limited ranges. The departures are due to secondary scattering of the light among the particles.

Even when the light is perfectly diffused, the exact geometrical theory leads to a complicated expression for the diffuse density, as shown by Channon, Renwick, and Storr*. A similar theory of the Tyndall intensity of a thick layer of dispersing medium is presented, which shows that the exponential equation of Wilke and Handovsky** is but a first order approximation for high dilutions and small depths. The exact theory is of little use in practise because small cells are used which introduce edge effects. The instruments are therefore limited to interpolation. The empirical calibration curves are linear over dilutions exceeding a hundred fold on double-logarithmic paper.

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*Phot. J. *58*, pp. 121–34, 1918.
**Ann. der Phys. *42*, pp. 1145–53, 1913.

L. E. Dodd (Introduced by F. K. Richtmyer) **University of California, Southern Branch, Los Angeles**

DISTRIBUTION OF THE TOTAL LIGHT INCIDENT UPON AN INFINITE PLANE, FROM AN EXTENDED PLANE SOURCE PARALLEL TO IT.

In measurements on the intensity of the light emanating from non-luminous matt surfaces, the experimental methods usually employed have used for the incident illumination either a concentrated source, where the beam is made parallel by collimation, or a somewhat extended source at a distance great enough to subtend at any point of the surface a small solid angle. In the present work, accepting Lambert's cosine law, at any rate as suitable here, formulas are obtained by integration for the case of an extended plane source having uniform brightness. The formulas give the intensity distribution for the simpler case of an infinite plane screen placed parallel to the source plane at a distance d from it. The intensity is that of the total light incident at any point of the plane screen. In general, the situation considered is that of a luminous strip with straight parallel edges but infinite length. Particular cases of this are the ones where the bright source field is 1) infinite, 2) semi-infinite (the infinite source plane being divided by a straight line into halves, one bright, the other dark), and 3) a strip of finite width, a. Graphs are drawn and discussed, including 1) semi-infinite field, 10 members of family, d as parameter; 2) bright strip of finite width, 6 members of family, parameterd, and 3) 9 members of family, parameter a; 4) corresponding graphs for a bright strip in an otherwise dark field and a dark strip in an otherwise bright field, 5) resultant intensity distribution of the total incident light for 1, 2, 3, and 4 bright strips of equal width and equal separation, b, and 6) resultant distribution for a large number of parallel equal strips where the dark interspaces have the same width as the bright strips, 5 members of family, parameter d (the strip widths are not taken sufficiently small to involve diffraction); 7) equal strips where d and a are constant, 5 members of family, parameter b; 8) parallel dark strips where d and a are constant, 6 members of family, parameter a; 9) checking of the work on resultant distribution by obtaining the same resultant curve through summing for a), n bright strips, and then b), n dark strips, for a definite value each of a, b, and d.

Arthur C. Hardy and Fred H. Perrin **Massachusetts Institute of Technology**

THE SENSITOMETRY OF THE BICHROMATED GELATIN PROCESS.

A sensitometric study has been made of a process wherein Eastman Slow Lantern Plates are sensitized in ammonium bichromate solution, exposed to light, etched in hot water, fixed in hypo to remove the silver halide, washed free from hypo, and dyed appropriately. This process is essentially that described by Mees for the production of colored photomicrographs, and is closely related to many color and photomechanical processes.

The physical theory of the process has been developed and used to predict qualitatively the shape of the characteristic curve and the effect upon this shape of alterations in the conditions under which the operations are conducted. The curve is much like that of a gelatino-bromide emulsion. The conditions studied were concentration of sensitizer, introduction of a light-restraining dye in the sensitizer, time and temperature of sensitization, conditions of drying, time of storage of plates, time and temperature of etching, time of dyeing and acidity of dye.

The details of the method followed and the results obtained cannot be presented satisfactorily in an abstract, but will be fully described in a forthcoming paper.

Bibliography:
Mees, Br. Jour. Phot. Col. Supp., *12*, p. 1; 1918.

I. C. Gardner and A. H. Bennett **Bureau of Standards**

THE COMPENSATION OF DISTORTION IN PHOTOGRAPHIC OBJECTIVES FOR AIRPLANE TOPOGRAPHICAL MAPPING.

Lenses to be used in taking airplane photographs for topographic surveying must be very free from distortion. A study of commercial lenses indicates that it is difficult to find lenses satisfactory in this respect. It is shown that in many cases the distortion in a lens may be satisfactorily compensated by a plane parallel plate used as an additional component of the lens. Data are given showing the effectiveness of the method. It is shown that the addition of the plane parallel plate is generally not detrimental to the other corrections of the objective. Experimental work is reported which justifies these conclusions.

A. H. Bennett **Bureau of Standards**

THE DISTORTION OF SOME TYPICAL PHOTOGRAPHIC OBJECTIVES.

In connection with an examination of lenses to be used in airplane topographical mapping, a careful study has been made of the distortion of a large number of high grade commercial photographic objectives. The apparatus designed for the measurement of distortion for infinite or finite object distance is described. The data show the distortion of the symmetrical anastigmat when the object is at an infinite distance, and also at unit magnification. At unit magnification, with a symmetrical lens there should be no distortion, but tests show sufficient distortion to affect the performance of the lens. Under this condition the distortion arises from lack of complete symmetry in the lens constuction. Data for the distortion of the unsymmetrical anastigmat (Tessar type) are presented. The results indicate that rather large variations in distortion exist among individual lenses of nominally the same construction. The case in which the axis of the lens is bent, the result of slight prismatic action of the system, is discussed and a method for determining its magnitude is described.

Otto Sandvik **Research Laboratory, Eastman Kodak Co.**

ON THE RESOLVING POWER OF PHOTOGRAPHIC MATERIALS.

The general practice among more recent workers in measuring the resolving power of photographic materials has been to photograph, in a reducing camera, on the particular material under consideration, some type of test object. Much of this work has been done with a test

object consisting of a series of pairs of parallel lines the distance between the centers of which varied. The resolving power is defined to be numerically equal to the reciprocal of the distance, in millimeters, between the centers of the pair of lines just resolved. It has been assumed in some cases that only the periodicity, that is, the distance between the centers of the lines, and and not the relative width of the lines to the separating opaque, was of importance. The present paper describes a new parallel line test object whose ratio of the width of the line to the opaque space varies from 0.40 to 40.0. The results obtained with this test object show a large variation in resolving power depending upon the value of the above ratio. For the range investigated, a linear relationship exists between the resolving power and the logarithm of this ratio.

The lack of agreement between the measurements made with the fan and the parallel line test objects have been due, in part at least, to the fact that the ratio of the line to the space of the former was usually slightly less than unity while that of the latter was frequently much larger.

The present paper will appear in full in J.O.S.A. & R.S.I.

L. A. Jones, V. C. Hall and R. M. Briggs **Research Laboratory, Eastman Kodak Co.**

ON THE RELATION BETWEEN TIME AND INTENSITY IN PHOTOGRAPHIC EXPOSURE. V.

The effect of different developers and development times upon the failure of the reciprocity law has been studied in detail. There is practically no difference in the curves of constant density for developers of widely different characteristics when development is carried to the same point with each developer. A change in development time has no effect on the shape of the curves of constant density but usually changes the position of optimal intensity.

The present paper will appear in full in J.O.S.A. & R.S.I.

INSTRUMENT SECTION

SOLARIMETERS AND SOLARIGRAPHS

SIMPLE INSTRUMENTS FOR DIRECT READINGS OF SOLAR RADIATION INTENSITY FROM SUN AND SKY

By Ladislaus Gorczyński

ABSTRACT

The paucity of solar radiation data is chiefly due to the lack of simple and portable instruments for direct readings. To fill this lack, there is described, under the name of "Solarimeter," a combination of a thermopile (modified Moll type), closed hermetically, under a hemispherical glass cover, and directly combined with an electrical measuring apparatus of a simple millivoltmeter-type. A system of two contact screws makes it easy to employ the solarimeter either for sun and sky observations on a horizontal surface or for pyrheliometric readings at normal incidence. For the latter a small pyrheliometric tube on a special holder is connected with the solarimeter box. All these new constructions should be considered as secondary instruments, which necessitate comparisons with normal pyrheliometers.

Directions for using and testing the solarimeter are given, in which is emphasized the employment of a solar screen for determining the sky radiation by Doctor Kimball's method.

A recording solarimeter (solarigraph) is also briefly discussed and the importance of sun and sky radiation measurements emphasized not only for meteorological stations, but also for agriculturists, botanists, for aviation (transparency of the atmosphere), and finally for photographic and medical purposes, by using violet and ultraviolet filters.

GENERAL REMARKS

Meteorologists are in full accord that in the series of meterological elements solar radiation takes the predominant place. Nevertheless, we note the strange fact that of the many thousand meteorological stations in the world a totally negligible number are making solar radiation measurements. In the large and well developed network in the United States only about six stations are making pyrheliometric readings or records regularly and, in other countries or continents the proportion is still lower.

The reason for this very unsatisfactory state of things is not an underestimation of the importance of solar radiation for the study of the atmosphere and its changes, but rather the lack of simple instruments for direct readings of this predominant meteorological element. It is obvious that for daily observations at ordinary meteorological stations and for general use for those interested (agriculturists, botanists, medical men, etc.) only very simple, portable and robust instruments can be employed. One needs an apparatus that will directly indicate the momentary values of radiation intensity, like a thermometer or other direct reading instrument. This objective is nearly gained by using thermopiles for solar radiation work.

The first thermoelectric pyrheliograph was used by Crova, professor at the University of Montpellier (France), some 40 years ago. Similar apparatus using thermopiles, recording or direct reading, but based on the thermoelectrical method, were constructed by Féry, Moll, Kalatine, Dorno, and recently by Linke, Henry, and others. Those usually employed at meteorological stations and research observatories are the Weather Bureau thermoelectric recording pyrheliometer devised in 1923 by Kimball and Hobbs at Washington, and the thermoelectric pyrheliograph constructed in Europe and described in the MONTHLY WEATHER REVIEW (June 1924) by the writer. But recorders intended for automatic notation of solar radiation values must necessarily possess a recording galvanometer with a clock mechanism, and in addition—for pyrheliographs recording radiation at normal incidence—a special equatorial mounting with another clock permitting it to follow the sun. Although by no means too difficult for regular use, all these recorders are relatively expensive and require daily service, which prohibits their use at simple meteorological stations.

The solarimeter is particularly adapted for stations of not only the higher order, but also for the simplest observing points.

On account of the extraordinary simplicity of reading the solarimeter the new instrument makes possible the realization of the wish of meteorologists of all countries to include solar radiation measurement in daily routine observations made at the same time as regular readings of air temperature, pressure, wind, etc.

Solarimeters are, moreover, especially useful in all sunny lands, such as the tropical and equatorial regions. Indeed the best example of the great need of simple solar radiation apparatus is the fact that the greater part of the meteorological stations in India are at present equipped with the so-called "radiation thermometers," consisting of a black bulb in vacuo. Only the existing extreme lack of simple apparatus for direct readings of solar radiation can explain why the "radiation thermometers" are still used, notwithstanding their well known and very serious meteorological defects.

Another important feature of the solarimeter is its adaptability for use with light filters. By employing a special solution, as, for example, copper sulphate in distilled water, the intensity of the violet and ultraviolet part of the spectrum can easily be obtained. Such an adaptation is especially valuable for medical climatology, actinotherapy, and also for photography, as it may be used for determining the proper time exposure. In addition to the copper-sulphate filters for shorter wave

lengths, other filters may be used. For the infrared portion of the spectrum, marble glass is very efficient. Further information concerning the question of light filters may be found in the paper "Light-filter measurements made by the Polish Solar Radiation Expedition to Siam in 1923, and at Touggourt in the Sahara Desert in 1924," published in the Quarterly Journal of the Royal Meteorological Society (*51*, pp. 210–218, April, 1926, London).

Finally, it is possible to apply solarimeters for aviation by connecting them with sensitive galvanometers; in this case one can rapidly obtain an idea of the transparency and thickness of clouds and fogs.

We give below the description of new direct-reading instruments, which are very simple even for the most inexperienced observers and several times less expensive[1] than the pyrheliographs. To these direct-reading instruments, designed for both solar and sky radiation, we propose to give the name of "Solarimeters" in order to distinguish them from pyrheliometers, which serve generally for radiation intensity of the sun at normal incidence.

THE SOLARIMETER: SOME DETAILS OF ITS CONSTRUCTION

The great simplicity of the solarimeter is evident by inspecting Figs. 1 and 2. This portable little instrument for measuring solar radiation consists of an hermetically closed (in dry air) brass cylinder containing a solarimetric thermopile under a hemispherical cover of special flint glass and directly connected with a convenient needle galvanometer of simple millivoltmeter type. The characteristic feature of the solarimeter is that its thermoelectric elements generating the current under the influence of solar radiation are directly attached to the galvanometric system (magnet with moving coil and needle), so that these two essential portions forming the complete apparatus are placed in the same solarimeter box. The cylinder with the thermopile, being fitted on the inner cover of the box, all connections are made inside.

The thermopiles especially made for solarimetric use consist of very thin plates of manganin and constantan of low resistance (about 8 ohms) with active junctions placed on a straight line in the center. In comparison with the original Moll type, it must be noted that the thermo-

[1] While thermoelectric recorders cost in round figures from $300 to $500, the solarimeters can be obtained for about $65 in Paris, where they are regularly manufactured by Richard, using the solarimetric thermopiles made by Kipp at Delft, Holland. The European construction would certainly be improved by combining the solarimetric thermopiles with American-made millivoltmeters, in view of the excellence of the latter instruments manufactured in the United States.

elements forming the rectangular solarimetric pile are straightened and uniformly covered with a special lacquer layer without intervals between separate thermoelements. This special construction and new arrangement of thermoelements with an unbroken and plane surface is essential for solarimetric work in order to avoid the changing influences of the oblique sun's rays resulting from their different incidence angles between horizon and zenith.

Though the solarimeter is designed primarily for direct readings of both sun and sky radiation, by merely changing the contact screws it is possible to connect the galvanometer, contained in the solarimeter box, with a pyrheliometer tube mounted in a special holder. With the tube normally directed to the sun, we thus obtain immediately a direct reading pyrheliometer.

The details of this construction are shown on the diagram Fig. 1.

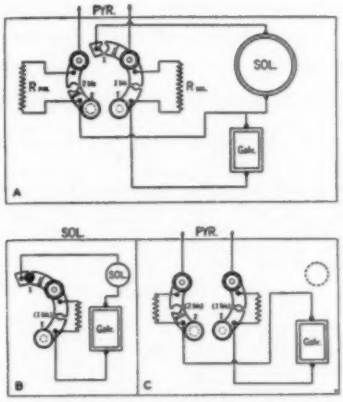

FIG. 1. *Diagram of connections in the solarimeter box.*

EXPLANATION OF SIGNS

Diagram A

Sol.—Solarimetric thermopile under hemispherical glass cover.

Galv.—Magnet with movable coil and needle.

1, 2, 2_{bis}—Alternative positions of the larger contact screw.

I, I_{bis}—Alternative positions of the smaller contact screw.

In the positions 2 and *I* the contact screws are in their neutral positions, and do not influence the electrical connections of the apparatus.

R_{sol} and R_{pyr}—Additional resistances which can be eliminated by putting in I_{bis} and 2_{bis} the respective contact screws.

Two circles with arrows each represent two contacts where the leads for pyrheliometric connections should be attached.

Diagram B.—Connections for solarimetric readings; I and I for ordinary use

For ordinary use the larger contact screw is placed at 1, the smaller one at *I* (its neutral position). With this position of the two contacts, the additional resistance R_{sol} is included.

If the smaller contact is removed from I to I_{bis}, the additional resistance is eliminated. The increase of the galvanometer deflection is, however, moderate in this case, the resistance R_{sol} being relatively small and chiefly used to give to the coefficient a certain desired value.

Diagram C.—Connections for pyrheliometric readings; 2 and I for ordinary use

Two movable contact screws remain in their neutral positions (smaller screw at I, large one at 2). With this position the additional resistance R_{sol} and R_{pyr} are both included. If the contact screws are removed from 2 to 2_{bis} and from I to I_{bis}, respectively, the two additional resistances are both eliminated. The galvanometer deflection is very largely increased in this case and such a combination may be used for small radiation values or when employing light filters. Other possible combinations (as, for example, 2_{bis} and I) are of secondary interest and will be only occasionally used; for every such combination a special coefficient must be determined in order to be able to convert the respective deflections into absolute value.

The pyrheliometric tubes used in connection with the solarimeter box are placed on a special holder (Fig. 2); the operation of directing them normally to the solar rays is very easily carried out by viewing a spot of light from the sun on the sight placed in the tube.

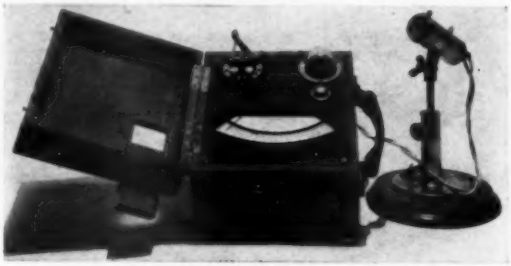

FIG. 2. *Solarimeter box for direct readings of the sun and sky radiation on a horizontal surface (connected also with a pyrheliometric tube on stand for the sun radiation intensity at at normal incidence).*

The thermopile used in the pyrheliometric tube is the same as that for solarimetric use, but without a hemispherical glass cover. In the opposite end of the pyrheliometric tube is a sphero-cylindrical lens, which magnifies the galvanometer deflections about four times.

The use of this lens is not obligatory, and an ordinary plane protecting glass would be sufficient to obtain good deflections. But the use of a sphero-cylindrical lens is not only very useful with low radiation values (and especially when employing light filters), but has other important advantages. The spherical and cylindrical radii are so calculated that the sun's rays are focused in the form of a narrow line covering just the active junctions of the thermopile, and by means of a rectangular diaphragm placed in the middle of the pyrheliometric tube the greater part of the thermopile remains in shadow.

Readings of the solarimeter are scarcely more complicated than the observation of an ordinary radiation thermometer. For making a measurement the box is placed horizontally, the slide in the cover opened, and the first determination of zero on the galvanometer scale made. One need not bring the needle to the true zero of the scale. The slide is then closed, the cover opened to expose the thermopile, and the deflection of the galvanometer needle again read. The thermopile itself acts in less than two seconds, but the final deflection of the needle is reached after a somewhat longer period, due to the lag introduced by the thick glass hemisphere. The cover is then closed, the slide opened, and the second determination of zero made as before.

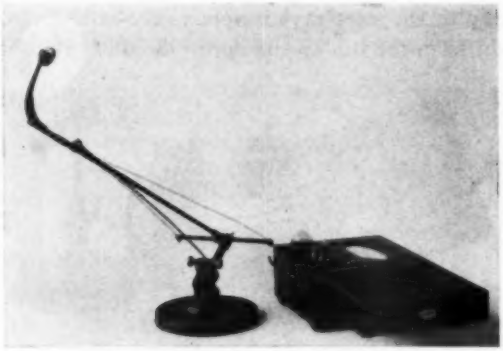

FIG. 3. *Solarigraph: Solarimetric pile under glass cover exposed outdoors to the sun and sky radiation and connected by leads with a recording millivoltmeter installed indoors.*

In case the zero readings differ, their mean value should be subtracted from the deflection produced by sun and sky. The differences are due in part to a slight heating of the glass hemisphere during the observation (due to the relatively great thickness and volume of the glass;) time is necessary, therefore, to permit the needle to return to its true zero. In some galvanometers (millivoltmeters) a slight tapping helps to accelerate the movements of the needle.

The scale of the solarimeter has 100 divisions (0–100) and additional resistances, R_{sol} and R_{pyr} (Fig. 1), are so chosen that the coefficients (value of one scale division in absolute units) represent certain determined and round numbers. The coefficients are generally expressed in gram-calories per square centimeter per minute, but a corresponding value for milliwatts per cm² or other unit can easily be deduced.

For test purposes the pyrheliometric tube is connected and the contact screws placed at 2 and I (their neutral positions); then two additional resistances R_{pyr} and R_{sol} are included. The deflections of the galvanometer needle when the pyrheliometer tube is used are very nearly proportional to values obtained simultaneously with a normal pyrheliometer. Dividing the value of the latter in gram-calories per minute per cm² by the number of divisions on the solarimeter scale the coefficient for the normal pyrheliometer is directly obtained. If the contact screws are placed at 2_{bis} and I_{bis} or other combinations are used (instead of at 2 and I), the value of the coefficient is smaller and must be determined by comparisons of readings with different resistances.

The value 0.02 (100 scale divisions equal to 2 gram-calories per minute per cm²) is generally used to convert the deflections (by pyrheliometric connections with the contact screws at 2 and I), in gram-calories per min. per cm². If the additional resistance R_{pyr} and R_{sol} are not conveniently chosen by the manufacturer, the observer may easily obtain this coefficient by inserting in series with the ordinary wire connection from the solarimeter box to the pyrheliometer tube several inches of high-resistance manganin wire lead. The proper length of this lead necessary to obtain the correct coefficient is obtained by the cut-and-try method, using a standard pyrheliometer for test purposes.

The testing of the solarimetric pile is somewhat more complicated than that of the pyrheliometric tube. The pile under its hemispherical glass cover, receives not only direct solar radiation, but also diffuse sky radiation; furthermore, solar radiation acting on the horizontal solarimetric pile is always smaller (proportional to cosines of the zenithal distance of the sun) than simultaneous intensity at normal intensity.

It follows that in order to compare the solarimeter readings, giving the total radiation from the sun and sky on a horizontal surface with simultaneous readings of a pyrheliometer exposed at normal incidence to the sun alone, the following computations must be made:

(*a*) The sky radiation must be separately observed by using a simple solar screen (see solar screen designed by Doctor H. H. Kimball, Fig. 4), which is placed between the sun and the solarimeter pile; in this case only the diffuse radiation from the sky gives the solarimetric deflection.

(*b*) The value of the sky radiation is then subtracted from the ordinary solarimetric readings (without solar screen), and thus the value of the sun's radiation only is obtained.

(*c*) The latter value if compared with the simultaneously obtained solar radiation value, using a normal pyrheliometer exposed perpendicularly to the sun's rays, by multiplying it by cosines of the corresponding zenithal distance of the sun, or, which comes to the same thing, by the sine of the sun's altitude. Thus the coefficient for solarimetric readings is directly calculated.

The following example shows clearly the necessary steps:

[American University, Washington, D. C., October 22, 1926]

(A)

11:26–11:35 a.m. (standard time) corresponding to 11:33–11:42 a.m., true solar time.

Zero position before reading	0.4
Solarimeter reading of sun and sky	28.0
Zero position after reading	.1
Solarimeter reading (corrected) of sun and sky	27.7

(B)

Solarimeter reading (deflection) with solar screen	2.9
Zero position (two readings, before and after sky deflection, mean value)	.2
Solarimeter reading (corrected) of sky only	2.7

(C)

Average value 11:33–11:42 a.m. (true solar time) of the solar radiation intensity obtained with a Marvin pyrheliometer (No. 3) was 1.17 gr. cal. per min. per cm.^{2} (zenithal distance of the sun at 11:38 a.m., true solar time, is 50°.1).

The coefficient K for solarimeter No. 4855 will therefore be—

$$K = \frac{1.17 \times \cos 50°.1}{27.7 - 2.7} = \frac{0.749}{25.0} = 0.03$$

The value 0.03 is obtained with additional resistance R_{sol} (contact screws at 2 and I). When this resistance R_{sol} is eliminated (by putting the small contact-screw in I_{bis} instead of I), the solarimetric coefficient will be smaller. It is generally nearly 0.02 in this case (contact screws at 2 and I_{bis}).

If a coefficient value greater than 0.03 is desired, it can be obtained by addition of a convenient length of small manganin lead to the resistance R_{sol}. In this case the additional leads must be attached to the special bobbin R_{sol} placed inside the solarimeter box. Although practically such tests should and will be made in an observatory and the solarimeters delivered to the observers with the corresponding coefficients it is not amiss to indicate the procedure for testing for observers who would not only be willing but who would have the proper standard normal instruments in their possession to enable them to repeat the standardization.

We may add that the solar screen of Doctor Kimball's design, illustrated in Fig. 4, was extensively used in 1914 at Mount Weather, Va., for standardizing a Callendar recording pyrheliometer where a glass cover is used. The valuable results of Doctor Kimball's painstaking investigations (see MONTHLY WEATHER REVIEW, August, 1914), give many hints for testing horizontally exposed pyrheliometers.

RECORDING SOLARIMETER (SOLARIGRAPH)

Though, as pointed out above, the solarimeters are made primarily as a portable instrument for direct short exposure to the sun, and not for permanent outdoor installation, they can also be adapted for recording purposes. (See Fig. 3.) In that case the same solarimeter pile is installed on a special holder, which should be permanently fastened at a convenient place outdoors.

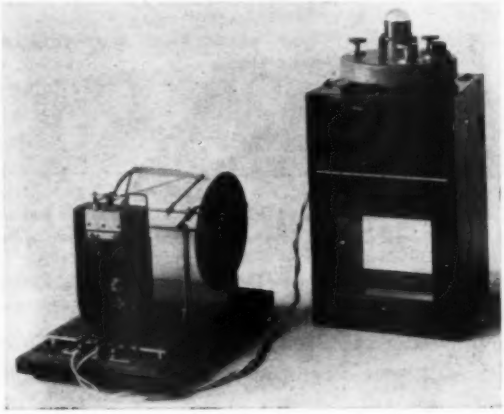

FIG. 4. *Solar screen used in connection with solarimeter for readings of sky radiation.*

The solarimeter pile, always hermetically sealed in dry air, can remain permanently in the open air without danger of condensation forming inside its glass cover, but the outer surface of the glass should be cleaned from time to time. By means of flexible leads this instrument is connected to the recording galvanometer, which should remain inside a building. The needle galvanometer (of a simple millivoltmeter type) mechanically recording, chosen for the solarigraphs, is similar to that used for the thermoelectric pyrheliographs manufactured by Jules Richard in Paris.

The new Richard recording galvanometers (millivoltmeters) are, however, specially adapted for solarigraphs. By using coils with low resistance, approximately the same as that of the solarimetric piles, a marked increase in deflections was obtained. The sensitivity of the solarigraph is sufficient to get a deflection even with cloudy weather; characteristic variations are obtained on the diagrams, provided the thickness and transparency of the cloud changes.

In Fig. 5 is shown a solarigraph record obtained on October 4, 1926. at the Solar Radiation Observatory of the U. S. Weather Bureau, American University, District of Columbia, where, through the courtesy of Professor Marvin, our solarigraph was calibrated. I am particularly indebted to Dr. H. H. Kimball, in charge of the Solar

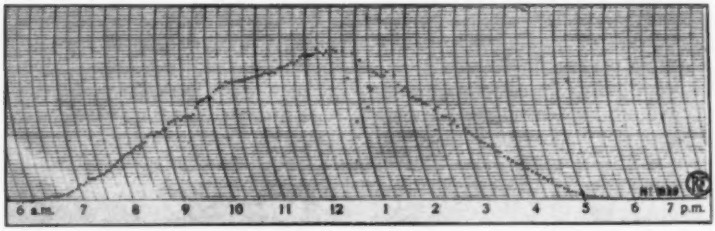

FIG. 5 *Record obtained with a solarigraph on October 4, 1926, at the Solar Radiation Observatory of the U. S. Weather Bureau, American University, District of Columbia.*

Observatory, and to his assistant, Mr. Irving F. Hand, for their kind help and very valuable suggestions during my stay at the Observatory.

The record of October 4, 1926 (Fig. 5), was obtained during a mostly clear day, although some clouds (visible between 12:30 and 1.30 P.M.) caused certain irregularities in the curve. Such a solarigram can be used for calculations, for instance, by planimetric methods, of the daily sums of solar and sky radiation on a horizontal surface.

Both direct-reading and recording solarimeters are made with two or more ranges, which permit the obtaining of greater deflections during cloudy or winter days with low sun. A very useful and important feature of the solarimeter is that it is able to give interesting records even on cloudy days, when the normal pyrheliometer gives no indication at all.

SOLAR OBSERVATORY U. S. WEATHER BUREAU
WASHINGTON, D. C.

AN ILLUMINATOR FOR USE IN METALLOGRAPHIC MICROSCOPY*

By Lewis E. Jewell

Two typical methods of illumination, each possessing certain advantages, are used in the photomicrography of opaque objects. The more common method employs *oblique illumination*. The light incident upon the object may come from a source at any angle of elevation above the plane occupied by the surface of the object, consistent with the construction of the microscope. The limiting angle depends upon the diameter of the objective tube and the working distance of the objective. The greater the focal length of the objective the greater may be the angle between the object plane and the incident illumination. The contrast obtainable is in general dependent upon the angular size of the source and its angular elevations above the object plane. A very small source and a small angle between the direction of the incident light and the plane of the object in general gives great contrast while low contrast is obtained by a large source and angles departing widely from grazing incidence. If the grain or structure of the object is relatively large satisfactory illumination is obtained in general by use of a source of large angular dimensions placed well above the plane of the sample. On the other hand if the textural details are small it is necessary to use a small source and angles approaching grazing incidence in order to render clearly the surface details.

A highly polished opaque surface is not well rendered by any method of oblique illumination in which the incident beam does not pass through the objective. This is because the light reflected specularly from the surface of the object does not enter the objective and the details seen in the microscope are due only to the very small amount of light which is scattered by the surface irregularities. This is particularly true of polished and etched metallic or smooth crystal surfaces. To obtain satisfactory rendition of such surfaces, especially when it is necessary to use relatively high magnifications, the light must be reflected into the objective and pass through the whole or part of the objective lens system. In this case the objective acts as a condenser. The resultant converging beam of light then falls upon the polished surface of the object and is *specularly reflected* back into the objective on the other

* Communication No. 291 from the Research Laboratory of the Eastman Kodak Co.

side of the axis, passes through the lens system to the occular, is brought to a focus and examined by the eye or photographed on a light sensitive material. Any elements of the surface not highly polished, or whose surfaces are not normal to the axis of the objective reflect less light into the objective and hence appear dark as compared with those portions which reflect the light specularly.

Specular reflection. Methods employing illumination of the object by light which passes down through the objective are usually, although incorrectly, referred to as *vertical illumination.* The object is illuminated by a bundle of rays condensed by the objective. Most of them are not incident perpendicular to the surface of the object but are reflected specularly by the smooth surface of the object into the opposite side of the objective. This method of illumination, or a modification of it, gives the most satisfactory results for metallic specimens which have been polished and etched to bring out the details of structure. The rendition obtained shows the surface structure which is due to variations of smoothness rather than to variations in brightness of various parts of the object. Those portions which are smooth and perpendicular to the axis of the microscope are rendered as areas of high brightness, while any areas which are less smooth or are inclined at some angle to the axis are rendered as dark areas.

Conical Illumination. Harry S. George in a paper "Conical Illumination in Metallography" (Trans. Am. Soc. for Steel Treating, Aug. 1923) described a method of illumination by which he secured for medium and high powers something approaching the relief effects ordinarily obtained with oblique illumination at low magnifications. The results were secured by obstructing the central portions of the beam of light which otherwise would have been reflected from the thin plate of glass placed just above the objective and inclined at an angle of 45° to the axis of the microscope. A preliminary form of illuminator was constructed embodying George's idea. The method has been somewhat modified and a procedure which gives excellent results has been established. A somewhat more simple device for obtaining the desired distribution of incident light has been constructed which eliminates many of the difficulties inherent in that proposed by him and gives excellent definition with a field remarkably free from haze due to scattered light.

When a plane glass plate is used as a reflector the proportion of light reflected by the glass surface is small and the central portions of the lens system reflect back a considerable amount of light producing flare

or field illumination. Surface imperfections and dust upon the plane glass mirror also scatter some light which adds to the brightness of the field haze thus decreasing appreciably the contrast of the image as seen in the microscope. The light reflected from the object after passing through the objective on its way to the ocular must again pass through the plane glass plate which reflects the light downward into the objective. It is evident that any optical imperfections in the glass of which this reflector is made will injure the definition of the resultant image. The opaque obstructing stops proposed by George reduce the lens flare from the central portions of the objective but are very troublesome to adjust and to keep in adjustment.

By using a 45° prism as a means of reflecting the light down through the objective some of these objectionable effects are reduced but other

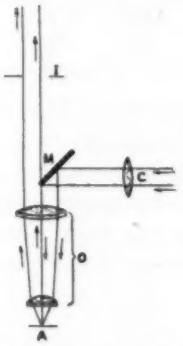

FIG. 1. *Specular reflection*

defects including a certain amount of chromatism are introduced. The illumination, however, is stronger.

A polished metal mirror covering one-half of the field may also be used. In this case half of the objective lens acts as a condenser, while the other half functions as an image forming lens. This gives illumination which is very strong but the flare due to reflection from the central zones of the lens is rather great. With a mirror having a straight edge and extending in to the axis of the microscope the specular illumination is relatively strong and tends to overwhelm any relief or contour effect which may be present due to the obliquity of the incident illumination. The diagram in Fig. 1 shows such a reflector inserted above the microscope objective. It will be seen that the illumination incident on the object *A* fills a solid half cone. The light returning through the opposite

half of the objective is almost entirely due to specular reflection and hence shows only those details of the object surface which result largely from difference in specular reflecting power. The method of making the essential elements is shown in the cross sectional drawing in Fig. 2.

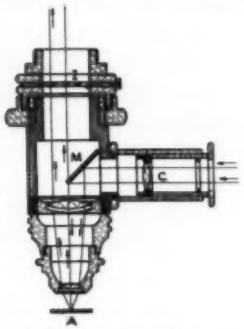

FIG. 2. *Specular reflection.*

Relief Illumination. Many of the objections to the above methods of obtaining specular illumination are largely eliminated by cutting a notch in the edge of the metal mirror. This is shaped like one-half of a prolate ellipse and appears as a semi-circle when viewed along the microscope axis. By bevelling the edge of the mirror which is introduced into the light beam complete clearance is obtained and the evil effects of

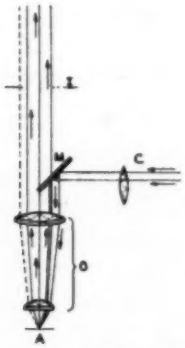

FIG. 3. *Oblique illumination.*

reflections from the edge of the metal are eliminated. This mirror is mounted at an angle of 45° so as to reflect the light, entering from the side, down through the objective. The diagram in Fig. 3 shows the way in which this metallic reflector is introduced into the optical system.

C represents a collimating lens from which a bundle of parallel light is incident perpendicular to the axis of the microscope. The mirror *M*, which is made of a thin piece of polished stellite is inserted as shown. Light incident on this mirror is reflected down into the objective and returns, after reflection from the object, through the other side *and*

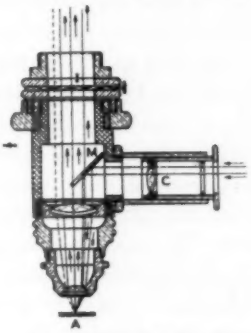

FIG. 4. *Oblique illumination*

through the central portion of the objective. The central portion of the objective is unobstructed since an elliptical shape notch is cut from the lower edge of the mirror. The form of the reflector used is shown at the right in Fig. 5. In Fig. 4 is shown a cross section through the complete objective as constructed to carry the reflecting mirror of this type. The side tube carrying the collimating lens *C* is slidable for

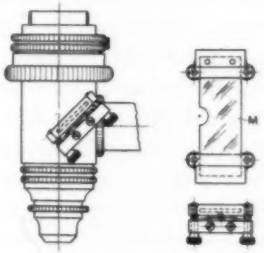

FIG. 5. *Mirror adjustment.*

purposes of adjustment. An iris diaphragm *I* is mounted above the objective in the upper part of the nosepiece. This is used for controlling the intensity of the specular component of the image forming light. The drawing in Fig. 5 shows an exterior view of the assembled nosepiece. The reflector is introduced through the slot *M* in a square box-

like section immediately above the microscope objective. Adjustment screws are provided which make it possible to position the reflecting surface perfectly with respect to the optical system.

Since the central portion of the mirror *M* is cut away the light entering the microscope tube is reflected only by the portions of the mirror surrounding this aperture. The cross section of the reflected beam is therefore represented by a semi-annulus. This is converged by the lens in the microscope objective and is incident obliquely upon the surface of the object. This incident illumination fills a space represented by one-half of a hollow cone. The light which is reflected from polished surface elements lying perpendicular to the optical axis returns through the opposite half of the microscope objective. It is evident, however, that no light thus reflected will return through the central zone of the objective. If, however, there are surface irregularities which diffuse or scatter the incident light, the light thus reflected may pass up through the central zone of the objective. Thus with this method of illumination the image forming light consists of two parts: (a) that which is specularly reflected from polished elements lying perpendicular to the optical axis and (b) that which is diffusely reflected by unpolished areas or surface irregularities. The outer zone of the objective transmits those rays which are specularly reflected while the central zone transmits the diffuse component. Now by closing the iris diaphragm *I* (See Figs. 3 and 4) it is possible to block out the outer zones of the optical system thus eliminating from the image forming light those components which have been specularly reflected. By closing the iris so that its aperture transmits only light from the central portion of the objective the image may be formed almost exclusively of diffusely reflected light. In this case the rendition obtained is similar to that obtained by oblique illumination. By opening the iris diaphragm the light which has been specularly reflected is allowed to pass and since in general it is of much greater intensity than the diffusely reflected component, the image has the quality of one formed entirely by specular reflection. By adjusting the opening of the iris to allow only a part of the specular light to reach the ocular any desired balance between specular and diffuse reflection may be obtained. This is termed *relief illumination.*

In order that the image field obtained by specular reflection shall be uniform in brightness and definition, it is necessary that the surface of the specimen being examined shall lie normal to the microscope axis. In some forms of microscope this condition is obtained by holding the surface of the specimen against a properly adjusted frame.

With microscopes of other construction a simple form of adjustable tilting table attached to the mechanical stage should be provided.

Theoretically the size of the notch cut in the edge of the reflector (see Fig. 5) should be adjusted to the focal length of the objective and the diameter of the objective lens. In practice it has been found that two sizes are sufficient, one being used for low power and the other for high power work. The smaller aperture will give a greater amount of specular reflection, more lens flare, less perfect resolution of the finer details, and inferior structural relief effects. If the aperture is unduly large, however, the decreased amout of specular reflection will tend to result in uneven field illumination but will give somewhat better resolution and more marked rendition of structural relief. Obviously the best possible result is only obtained when the size of the notch is such as to give a perfect balance between the two effects.

The effect produced by varying the size of opening in the iris is somewhat different. Reducing the size of this opening diminishes the proportion of specular reflection thus rendering more prominent the structural relief. Too great a reduction in size, however, decreases the field brightness unduly and may result in uneveness. Increasing the size of the iris opening increases the image brightness due to specular reflection and consequently overwhelms the details shown by the diffusely reflected light. This results in a great decrease of the relief appearance.

The Mirror Surface. The smoothness or degree of polish given to the reflector surface has an important influence upon the quality of the image. A highly polished mirror gives the best resolution of fine details especially near the center of the field. In the outer zones a peculiar scintillating effect is sometimes observed which is somewhat objectionable. A very dull reflector surface produces excessive scattering of light and the detail under examination is indistinct and lacking in contrast. The best result is obtained with a surface that may best be described as a very high perfect polish that has been just slightly dulled by use of an extremely fine abrasive.

Illustrations. The photomicrographs reproduced in Figs. 6 to 13 illustrate the capabilities of this type of illumination. The examples were selected for their varying character and represent materials which are rather difficult to render satisfactorily. The illustrations as shown are approximately one-half their original size so that the values of magnification as indicated in the captions are really twice as great as in the reproduced illustrations.

EASTMAN KODAK CO.,
ROCHESTER, NEW YORK.
October, 1926.

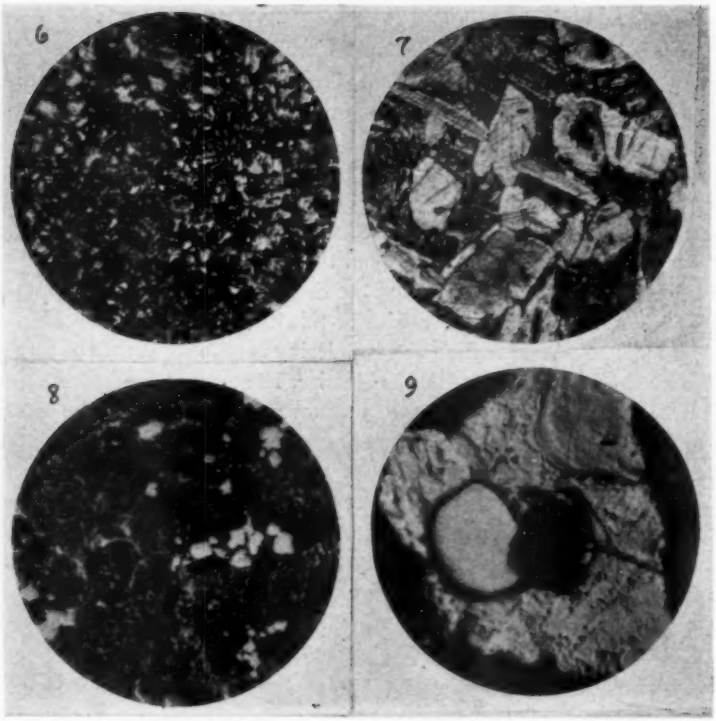

FIG. 6. *An alloy of tin, copper, antimony, and bismuth possessing a very low coefficient of expansion. Magnification 109 diameters.*

FIG. 7. *Aluminum bronze. This sample was very difficult to etch and the final surface shows many fine scratches. Magnification 528 diameters.*

FIG. 8. *Tungsten tool steel. Magnification 528 diameters.*

FIG. 9. *Section of meteorite from Llaro del Estacado, Texas. Magnification 528 diameters.*

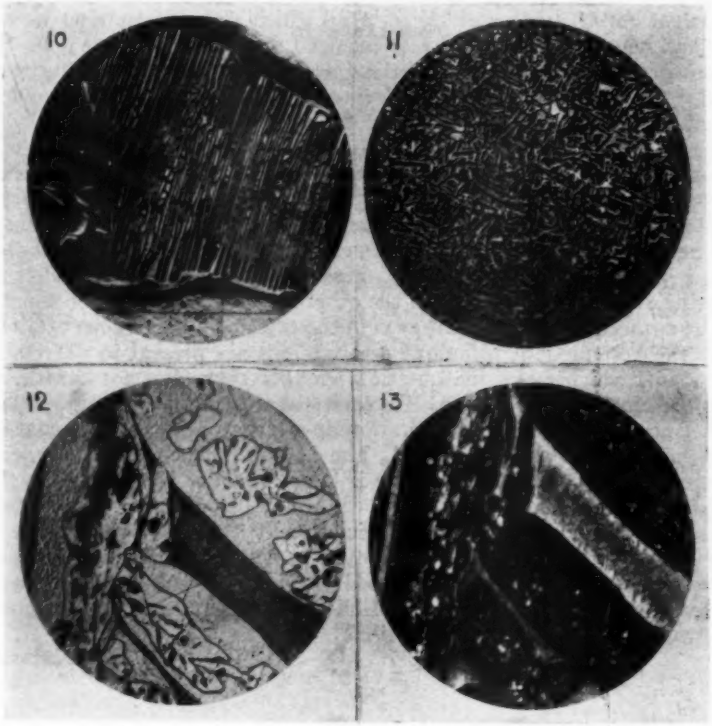

FIG. 10. *Section of meteorite from Shrewsbury, Pa. Magnification 199 diameters.*

FIG. 11. *Meteorite from Finmarken, Norway, showing a very intricate pattern and fine structural detail. Magnification 109 diameters.*

FIG. 12. *Meteorite from Alexinatz, Serbia. This photomicrograph was taken by relief illumination. Magnification 23 diameters.*

FIG. 13. *This shows a micrograph of the same area of the sample shown in Fig. 12. In this case, however, the illumination was of the ordinary oblique type. The parts having a high polish are shown as bright areas in Fig. 12 but with the oblique illumination used in this figure these areas are rendered as black.*

The extraction of electrons from cold thoriated tungsten (wires of 12.3μ diameter) by the sole agency of intense applied electric fields, unassisted by heat or irradiation is shown to be quite practicable with fields which at the metal surface exceed $2 \cdot 10^6$ volts/cm. The "critical" field strength sufficient to produce a just perceptibly large current (10^{-11} amp) and the rate at which the current rises as the field strength is further increased depend to a marked extent upon the previous history of the metal; heating to temperatures ranging from 400° to 1700°K decreases the former and increases the latter, while intense heating produces changes in the opposite sense. Similarly, if the field strength is gradually raised to a value at which there is a considerable current and then lowered again, the descending current-vs-field strength curve lies lower than the ascending one, but thereafter is reproducible if the maximum field strength already attained is not overpassed. The increases in critical field strength are attributed to a flattening-out of slight roughnesses on the metal surface, effected in the one case by heat and in the other by positive ion bombardment. The authors thus admit that even in the extremely high vacua attained by the best modern technique positive ions are present in detectable amount, which raises the question whether they may not contribute to the ejection of electrons. Decreases in critical field strength, when they occur, are ascribed to alterations in gas-content or thorium-content of the surface-layer of the metal. The effect is independent of temperature from 300° to 1000°K, which is taken to mean that the extracted electrons are initially stationary in the metal; but when the temperature (*ca.* 1100°K) at which thermionic current should be perceptible is actually reached, the current increases in a proportion far larger than the mere addition of the calculated "saturation" value of thermionic current should supply.—[R. A. Millikan and C. F. Eyring (Pasadena); Phys. Rev., (2), *27*, pp. 51–67; 1926.]

KARL K. DARROW.

ON THE MEASUREMENT OF RESOLVING POWER OF PHOTOGRAPHIC MATERIALS*

By Otto Sandvik

The resolving power of a photographic material may be defined qualitatively as the ability to show fine detail in the picture. Many methods of direct measurement and methods which have been suggested by general definitions have been used to establish quantitative values for resolving power. A very complete historical treatment is given by Ross.[1] The practice generally among more recent workers has been to photograph in a reducing camera some type of test object on the photographic material under consideration. The fan test object[2] consists of alternate clear and opaque sectors of small, equal, angular openings. The parallel line test object[3] has a series of pairs of parallel lines with varying separation. The resolving power is defined as the number of lines per millimeter which are resolved. It has been assumed in some cases that only the periodicity, that is the distance between the centers of the two lines, and not the relative width of the lines to space effects the resolvability of a pair of lines.

The present paper gives some results obtained with a parallel line object designed to test the validity of the above assumption. This test object is shown in Fig. 1. This consists of sixteen groups of parallel lines. Each group contains three opaque spaces and two transparent lines. The distance between the center of a line and the center of an adjacent space will be designated as d. The value of d is the same for all of the line groups in the test object.

The ratio of the width of the line to that of the space is different for each group of lines. This ratio for convenience will be designated as A.

$$A = (\text{width of line})/(\text{width of space})$$

The values of A, which vary from 10.7 to .13, are shown in Table 1. A number of test objects exactly similar in form to that shown in Fig. 1

* Communication No. 289 from the Research Laboratory of the Eastman Kodak Company.

[1] Ross, F. E., The Physics of the Developed Photographic Image, Chap. IV, Monograph No. 5 from the Research Laboratory of the Eastman Kodak Company.

[2] Mees, C. E. K., Physics of the Photographic Process, J. Frank. Inst., *179*, p. 141; 1915.

[3] Ross, F. E., loc. cit., p. 146.

but differing in size were made. The value of A for any particular group of lines is therefore the same in all of the test objects regardless of their

TABLE 1. *Eastman 33 plate*

Test object		Resolving power			
A	log A	$T_d=1$	$T_d=2$	$T_d=4$	$T_d=8$
10.7	1.03	14	14	14	20
7.94	0.90	20	—	20	—
5.75	0.76	28	20	—	—
4.68	0.67	—	—	—	28
4.27	0.63	—	—	28	—
3.72	0.57	—	28	—	—
2.51	0.40	42	—	—	—
2.30	0.36	—	—	42	42
1.82	0.26	53	42	—	—
1.20	0.08	—	—	53	53
1.00	0.00	—	53	—	—
0.79	1.90	70	—	—	—
0.55	1.74	—	—	—	70
0.40	1.60	83	70	70	—
0.21	1.32	—	83	83	83
0.13	1.10	—	—	—	—

size, but the spacing, d, is different being directly proportional to the size of the test object as a whole. Thus d is a constant for all of the line groups in any one test object. The value of d, for the test objects

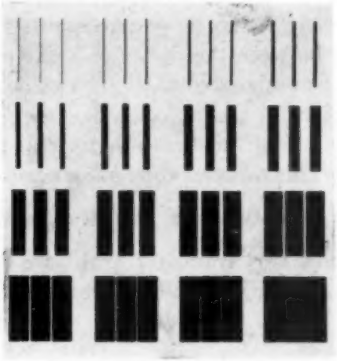

FIG. 1. *Parallel line test object.*

of different size, was varied over a range sufficiently wide so that measurements could be made on practically all photographic materials from the lowest to the highest resolving power.

An image of the test object was formed on the photographic naterial being studied in a reducing camera at a magnification of .05 (1/20). By microscopic examination of a series of images resulting from the use of a number of test objects varying in periodicity, d, the resolving power of the material for line groups of various ratios, A, was determined. If d (expressed in mm) is the spacing constant of the test object which is found to be just resolved; then resolving power, R, in terms of lines per mm is given by the equation,

$$R = \frac{1}{d} \cdot \frac{1}{.05}$$

It has been shown by Huse[4] that resolving power varies enormously with exposure. At low and at high exposure values resolving power is relatively low, while a marked maximum is obtained at intermediate exposure values. This variation in resolving power may amount to 60 per cent (or more) of the maximum value. It is customary in specifying resolving power of a material to give the maximum value, this being the one obtained by use of the *optimal* exposure. In order to determine experimentally the optimal exposure it is obviously necessary, in making reduced photographs of the test object, to vary the exposure over relatively wide limits.

Development time also has an influence upon resolving power.[4] Since it is desirable to determine whether the relation between the value of resolving power and the periodicity of the test object used in its measurement depends upon time of development, it is necessary to make measurements on negatives which have been developed for different times. The extent to which a photographic material is developed is usually expressed with entire satisfaction in terms of gamma, the slope of the straight line portion of the characteristic curve $D = f(\log E)$. Resolving power, however, depends upon additional development factor such as reducing agent,[4] constitution of the developing solution, etc. Development conditions, in the case of resolving power work, are best defined therefore by giving the consitution of the developer, the temperature at which it is used, and time of development. In this work a solution made up according to the following formula was used, its temperature being adjusted to 68°F.

[4] Huse, K., Photographic Resolving Power, J.O.S.A. & R.S.I., *1*, p. 119; 1917.

M. Q. Process Developer

Elon	1 gram
Hydorchinon	9 "
Sodium Sulphite	75 "
Potassium Carbonate	25 "
Potassium Bromide	5 "
Water to	1000 cc

The procedure followed in the study of a given material was to make a series of exposures using each of the different sized test objects. With each test object a series of nine exposures was made, the exposure time increasing by consecutive powers of 2. Four such series of exposures were made on each material with each test object. One of these series was then developed for one minute and the others for 2, 4, and 8 minutes respectively.

In Fig. 2 is shown an enlargement from a negative resulting from one of the series of exposures described above. The group in the lower left hand corner shows the result obtained with the minimum exposure

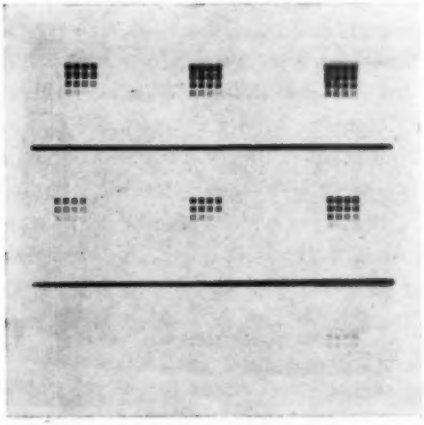

FIG. 2. *A series of images of the parallel line test object on Eastman 40 emulsion, exposures increasing by powers of two.*

which may be designated arbitrarily as 1. The group immediately to the right had an exposure of 2, the next 4, etc., the group in the upper right hand corner having had an exposure of 256 times that in the lower left hand corner. Fig. 2 is from exposures made on Eastman 40 plates.

An inspection of Fig. 2 shows the great effect on resolving power produced by variation in exposure. This figure also demonstrates emphatically that the optimal exposure, from the standpoint of obtaining maximum resolving power, depends to a great extent upon A, the ratio of line to space in the test object used.

Each step on the negatives obtained as described above was examined under the microscope and in this way the resolving power of the material for groups of parallel straight lines having various values of A were obtained. The data relative to Eastman 33 plates are shown in Table 1. In the columns under "Test Object" are given the data relative to the ratio of line to space. In the columns under "Resolving Power" are tabulated numbers which indicate the lines per mm resolvable for the various values of A as determined from plates which were developed to different extents. It is now possible to determine the relation between resolving power, for a fixed time of development, and A, the ratio of

TABLE 2. *Eastman 40 plate*

Test object		Resolving power			
A	log A	$T_d=1$	$T_d=2$	$T_d=4$	$T_d=8$
10.7	1.03	14	14	14	14
7.94	0.90	20	—	—	—
5.75	0.76	—	20	20	20
3.72	0.57	28	—	28	28
3.02	0.48	—	28	—	—
2.30	0.36	42	—	—	—
1.20	0.08	—	42	42	42
1.00	0.00	53	—	—	—
0.79	1.90	—	—	53	53
0.55	1.74	70	—	—	—
0.40	1.60	—	53	—	—
0.21	1.32	—	70	—	70
0.13	1.10	—	—	70	—

line to space. In Fig. 3 the data from Table 2 are plotted. It will be noted that by plotting resolving power as a function of log A a straight line relationship is obtained. The curves shown in Fig. 3 are for the different times of development. To avoid confusion between the value for different times of development these are displaced laterally, the actual relation to the log A scale being indicated by the short vertical line drawn through each curve and designated as 0.0 Now by reading the ordinate value of the curve where log A is equal to 0.0 ($A=1.0$) the

TABLE 3. *Eastman speedway plate*

Test object		Resolving power		
A	log A	$T_d=2$	$T_d=4$	$T_d=8$
5.75	0.77	14	—	—
4.68	0.57	20	20	14
2.20	0.34	28	—	—
1.20	0.08	—	28	—
0.79	$\bar{1}$.90	—	—	28
0.55	$\bar{1}$.74	42	—	—
0.38	$\bar{1}$.58	53	42	—
0.28	$\bar{1}$.44	—	—	42
0.13	$\bar{1}$.10	—	53	53

TABLE 4. *Eastman superspeed portrait film*

Test object		Resolving power		
A	log A	$T_d=2$	$T_d=4$	$T_d=8$
10.7	1.03	14	14	14
7.94	0.77	20	20	20
4.68	0.57	28	28	—
2.51	0.40	—	—	28
1.20	0.08	42	42	42
0.79	$\bar{1}$.90	53	—	—
0.55	$\bar{1}$.74	—	53	53
0.21	$\bar{1}$.32	70	—	—

TABLE 5. *Eastman process plate*

Test object		Resolving power
A	log A	$T_d=1$
10.7	1.03	20
5.75	0.76	28
2.51	0.40	42
1.20	0.08	53
0.55	$\bar{1}$.74	70
0.21	$\bar{1}$.32	83

resolving power of the material, defined in terms of the number of lines per mm resolved when the width of the line is equal to the width of the space, can be obtained. These values are shown in the first line of Table 6.

In Tables 2 to 5, inclusive, are given the data relating to other photographic materials. These data are shown graphically in Figs. 4 to 7. In all cases the relation between resolving power, for a fixed time of development and log A, is represented satisfactorily by a straight line.

TABLE 6.

Material	Resolving power for $A=1.0$				
	$T_d=1$	$T_d=2$	$T_d=8$	$T_d=4$	mean
Eastman 33	65	54	60	58	59
Eastman Process	58	—	—	—	58
Eastman 40	57	45	46	48	49
Eastman Speedway	—	37	30	28	32
Superspeed Portrait	—	47	45	45	46

The slope of the lines for any particular material does not vary to any great extent with time of development although there is a distinct tendency in some cases for the shorter times of development to give somewhat steeper curves than the longer times. A much more extended study of the subject is required to establish the reality of this variation of slope and, in case it is definitely established, to determine its significance

It appears also from the data on hand that in general the materials of high speed give steeper curves ($R=f(\log A)$) than those at low speed. It seems probable that this variation of slope is related in some way to grain size and to distribution of grain size and grain sensitivity. This phase of the subject must be studied much more extensively before any definite correlation between the slope of these curves and sensitivity, grain characteristics, or slope of the characteristic curve ($D=f(\log E)$) can be made.

In Table 6 the value of resolving power for a test object in which A is equal to 1.0 are shown. These values are read directly from the curves in Figs. 3 to 7 inclusive. As noted previously the shorter times of development show a tendency to give a somewhat higher resolving power than the longer. In practical work where high contrast is a requisite it is usually impossible to take advantage of this high resolving power given by short development times.

The data presented at this time establish definitely the direct relationship between the value of resolving power and the ratio of width of line to that of space in the test object used for its measurement. This vari-

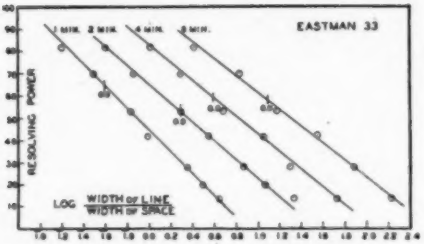

FIG. 3.

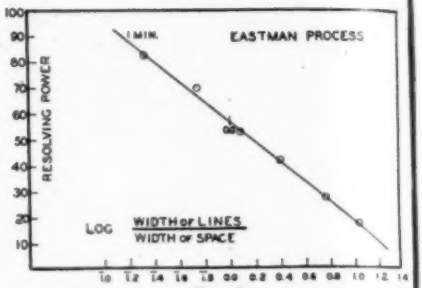

FIG. 4.

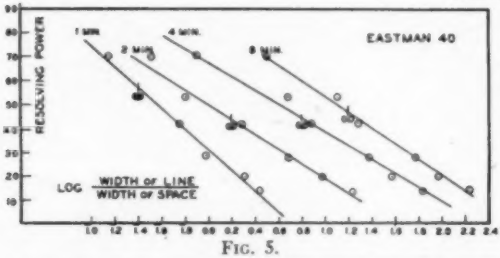

FIG. 5.

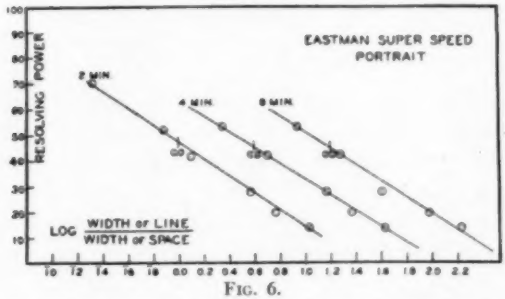

FIG. 6.

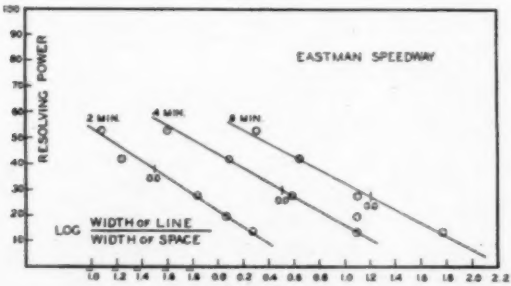

FIG. 7.

FIGS. 3–7. *Curves showing the relation between resolving power and the logarithm of the ratio of the width of the transparent line to the opaque space for different times of development. The vertical index marked 0.0 indicates the point on the curve where the value of the logarithm of the ratio is zero.*

ation of resolving power is large, being in some cases eight fold (10 to 80) for ratio values ranging from .013 to 10.0. It is obvious, therefore, that any value of resolving power determined by any method employing a test object of the line type either converging (fan) or parallel, it is quite meaningless unless accompanied by a definite specification of the ratio value A.

The lack of agreement[5] between the values of resolving power obtained with the fan test object and the parallel line test object is partly due to the fact that in the latter the width of the line was frequently much less than the width of the space. This, however, is not sufficient to account entirely for the large differences which have been observed.

The fan shaped test object is the most convenient to use for routine resolving power determinations and, although a parallel line test object, in which the line and space are equal in width, will better serve as a standard, a fan test object could be designed by making the angular width of the opaque sector larger than the transparent sector, so that resolving power values obtained with the two test objects would be equal.

Considerable difficulty was experienced in making test objects sufficiently small that would have the desired quality. A new resolving power camera is now being constructed which will have a reduction of 60 diameters as compared to the present one of 20 diameters. With this new camera the test objects can therefore be three times as large for equivalent resolving powers. When this camera is completed other phases of the problem will be investigated.

EASTMAN KODAK RESEARCH LABORATORY
ROCHESTER, NEW YORK
OCTOBER, 1926.

[5] Ross, F. E., loc. cit., p. 146.

L-emission series of mercury.—Measurements upon twenty lines ranging in wave length from 1420 to 836X, given to four or five significant figures, were made with a tube of Coolidge type having as target an amalgamated surface of Cu prepared in a peculiar way. Measurements have previously been made by Coster upon the elements adjoining mercury in the Periodic Table, so that the authors are able to present a graph showing the $\sqrt{\nu/R}$ values of several lines over the range of atomic numbers from 77 to 83 inclusive; the accuracy appears to be high, the points lying closely upon straight lines. The intersection of two of these lines at atomic number 80 is very clearly shown; the line called β_3 is of higher frequency than the line called β_8 for elements of greater nuclear charge than Hg, indistinguishable from β_8 in the spectrum of Hg, and is the lower in frequency of the two for elements of lower nuclear charge. It would be advantageous for writers to designate the x-ray emission-lines, when practicable, by the terms between which they are combinations.—[C. E. Eddy and A. H. Turner (Melbourne); Proc. Roy. Soc., *A 111*, pp. 117–124; 1926.]

KARL K. DARROW.

Instance of an unimolecular reaction.—The time-interval required for any given fraction of a quantity of acetone to dissociate is found (by measuring the rate of increase of pressure in the tube into which the acetone is introduced) to be independent of the density of the gas and of the surface-area of solid silica in contact with it. (The values given for such time-intervals at various gas-densities are rather scattered, but they show no trend). The dissociation is therefore regarded as a pure unimolecular reaction. The rate increases rapidly with temperature. Even at one of the lowest temperatures employed (835° K) and at 760 mm Hg the number of molecules dissociating per unit time is some five orders of magnitude greater than the number of intermolecular collisions calculated with a plausible value of molecular radius. All proposed theories of the agency effecting the dissociations are unsatisfactory.—[C. N. Hinshelwood and W. K. Hutchison (Oxford); Proc. Roy. Soc., *A 111*, pp. 245–257; 1926.]

KARL K. DARROW.

A PHOTOGRAPHIC METHOD OF SPECTROPHOTOMETRY IN THE RED AND INFRARED*

By A. L. Schoen

The advantages of photographic methods of spectrophotometry have been critically discussed in several papers and reports in this journal. The reports of the O. S. A. Progress Committee on Spectrophotometry[1] have reviewed the merits of practically all of the useful methods and the recent paper by Jones on "A New Method for Photographic Spectrophotometry"[2] summarizes concisely the precautions which must be taken when using photographic materials in making spectrophotometric measurements.

In general emphasis has been placed on work in the visible and ultraviolet parts of the spectrum and to the writer's knowledge very little, if any attention has been given to the use of photographic materials for making measurements in the infrared region. Undoubtedly this is due to the fact that photographic materials of satisfactory spectral sensitivity have only recently become available. Plates sensitized with Dicyanine have been used for photographing spectra but they retain their maximum sensitivity for a relatively short time and are subject to a considerable variation in sensitivity over the plate unless one is

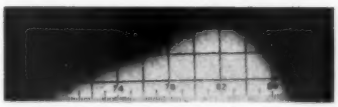

Fig. 1. *Wedge spectrum photographed on plate sensitized with Neocyanine.*

skilled in sensitizing technique. With the introduction of the new sensitizing dye termed "Neocyanine[3]" it became possible to photograph spectra without difficulty to a wave length of 900 mμ, Fig. 1, and when hypersensitized, to wave length 1000 mμ. These plates are available commercially, they keep well, and require no special treatment when developing them.

* Communication No. 293 from the Research Laboratory of the Eastman Kodak Company

[1] Spectrophotometry. J.O.S.A., *10*, p. 222; 1926, *11*, p. 359; 1925.

[2] Jones, L. A. A New Method for Photographic Spectrophotometry, J.O.S.A., *10*, p. 561; 1925.

[3] Dundon, M. L., Schoen, A. L., Briggs, R. M., Neocyanine, A New Sensitizer for the Infrared, J.O.S.A., *12*, p. 397; 1926.

The spectrophotometric characteristics of a large number of dyed gelatine filters have been measured in this laboratory and these data have been published in the booklet "Wratten Light Filters." The spectral range included by these published data is from 200 mμ to 700 mμ. The literature of the subject contains data relating to many different varieties of colored glasses which are commercially available and to some colored solutions of use in absorbing certain wave lengths. In general these data cover about the same range as that mentioned above and very little reliable information relative to the absorbing characteristics of such materials in the region between 700 mμ and 1000 mμ is available.

The increasing use of panchromatic photographic materials[4] which have appreciable sensitivity out to 760 mμ and also special materials sensitive to the infrared region makes it desirable to have available data relating to the selective absorption of filters in this region of longer wave lengths. Such quantative information is of use in connection with such problems as the production of "night" or "moonlight" effects by photographing scenes illuminated by sunlight,[5] biological experiments dealing with the effect of radiation on various organisms,[6] the use of infrared radiation for signalling purposes, light absorption in relation to chemical constitution, etc.

Considerable data on the infrared transmission of dyes and filters have been obtained with a Hilger spectrometer equiped with a thermopile and high sensitivity galvanometer. This method involves however some labor and a room and surroundings more or less free of disturbances. For the denser filters it was necessary to use a light source of high intensity in order to obtain sufficient energy around 700 mμ to give satisfactory galvanometer readings. This high intensity often caused excessive heating of the samples, in particular the dye solutions, and sometimes a fading of the dyes resulted before the test was finished.

With the advent of photographic materials sensitive to the infrared region (700 to 1000 mμ) it is obvious that a photographic method of making spectrophotometric measurements in this region can be used. The apparatus which has been constructed for this purpose is shown in Figs. 2 and 3. It consists of a three-prism spectrograph, *S*, made by

[4] Jones, L. A., and Crabtree, J. I., Panchromatic Negative Film for Motion Pictures, Trans. S. M. P. E., Oct. 1926.

[5] Ball, J. A., Trans. S. M. P. E., No. 22, p. 21; 1925.

[6] Luckiesh and Pacini, Light and Health, Pub. by the Williams & Wilkins Co., 1926.

Heele at the entrance slit of which is mounted the polarization photometer, Fig. 4, made by Bellingham and Stanley.[7] The optical axis of the polarizing prisms (A and B) are inclined and at their point of

FIG. 2. *Arrangement of spectrograph, photometer, and high intensity arc for spectrophotometry.*

intersection is placed the light source. By means of a suitably designed totally reflecting prism the beam B is rendered parallel to A and in this way the lower part of the slit is illuminated by light which passes

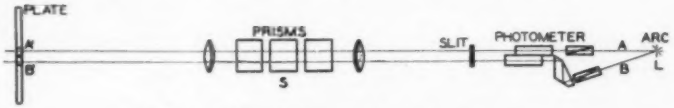

FIG. 3. *Schematic diagram of spectrophotometer.*

through the system B. The optical system of the spectrograph therefore forms on the plate plane two spectra adjacent to each other for one of which the radiation is furnished by the system A and for the

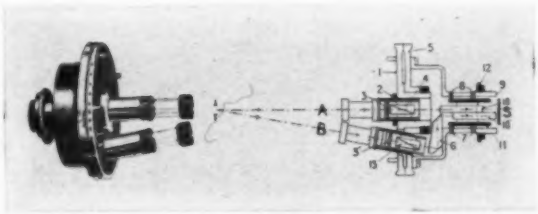

FIG. 4. *Bellingham and Stanley polarization photometer.*

other by system B. By rotating the nicol in system A about its optical axis the intensity of A′ spectrum can be controlled and adjusted to any desired value relative to that of spectrum B'.

In order to do spectrophotometric work satisfactorily in this region it is necessary to employ an optical system giving relatively high dis-

[7] Spectrometric Apparatus, Bellingham & Stanley Ltd., 71 Hornsey Rise, London N. 19.

persion in order that the radiations of different wave lengths may be separated sufficiently for convenient precise measurement. Using a system of great dispersion it is difficult to obtain sufficient energy density in the spectrum. The success of the method here described depends largely on the use of a light source of extremely high intrinsic brightness thus giving relatively high energy density in the spectrum formed by the dispersed radiation. This light source, L, (Fig. 3) is a Sperry 12" submarine type "D" high intensity arc[8] operating on 110 volts D.C. and drawing a current of 35 amperes. It is entirely automatic in operation and according to Bassett[9] the crater of this arc slightly exceeds the sun's disc in intrinsic brightness, the value quoted for this factor being 920 candle power per sq. mm. This light source has been found entirely satisfactory although it is subject to some variation in brightness with time. Measurements indicate that the crater brightness varies by approximately ± 5 per cent. The period of this variation is relatively short however, so that if the brightness is averaged over a period of several seconds the average value from one exposure to another is more constant than indicated by the above value.

The experimental procedure for obtaining spectral absorption data is essentially that outlined by Howe[10] and others who have used the Hilger spectrophotometer and quartz spectrograph. The sample to be measured (solution or filter) is placed in the test beam BB', Fig. 3, and a series of spectrum photographs are made. Previous to the insertion of the sample the system is so adjusted that when the plane of the polarizing nicol A is parallel to the plane of the analyzing member in the path AA' the two spectra, formed side by side on the photographic plate, are of equal intensity. Now by rotating the polarizing prims A the intensity of the transmitted spectrum can be reduced to any desired extent. The rotation of the polarizing prism A therefore is equivalent to the insertion of a known density in the beam AA'. After inserting the unknown in the beam BB' a series of photographs is made with the polarizing prism A set so as to be equivalent to a series of definitely known density values. These settings for any desired series of density values are computed from the relation $D = \log(1/\cos^2 A)$, where D is the

[8] Made by the Sperry Gyroscope Co., Brooklyn, N. Y.

[9] Bassett, P. R., The High Power Arc in Motion Pictures, Trans. S. M. P. E., No. 11, p. 79; 1920.

[10] Howe, H. E., On a Modification of the Hilger Sector Photometer Method for Measuring Ultraviolet Absorption and Its Application in the Case of Certain Derivatives of Fluoran, Physical Review, *8*, p. 674; 1916. Bureau of Standards, Scientific Paper No. 440 and Technologic paper 148.

density and A is the angle between the planes of the polarizing and analyzing prisms. Density is defined by the equation $D = \log(1/T)$ where T = transmission factor.

In the following table a typical record for a test of a solution of Kryptocyanine is given to show working data for the photometer.

TABLE 1

Density	Photometer setting corrected for absorption in photometer	Exposure in seconds
0	36.0°	5
.1	43.5	5
.2	49.8	10
.3	54.9	20
.4	59.1	40
.8	71.2	60
1.2	78.3	90
1.6	82.6	120
2.0	85.3	180

After development of the plate the wave lengths for equal photographic density in each pair of adjacent spectra are determined,

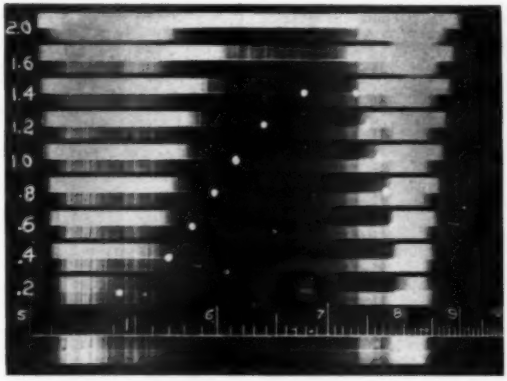

FIG. 5. *Absorption spectrum of a solution of "filter blue green" (1 in 15000) showing by dots the wave-lengths of equal photographic density.*

Fig. 5, and then plotted against the corresponding densities. It should be noted that this method is free from errors due to failure of the reciprocity law and to intermittency effects. Furthermore, the equality of density is determined at points immediately adjacent on the photographic plate thus eliminating any possibility of error due to variation

in the sensitivity of the photographic plate over its surface and to variation in the extent to which the exposures are developed.

The question may arise as to the possible selectivity of the calcite prisms in the photometer. This appears from our investigations to be

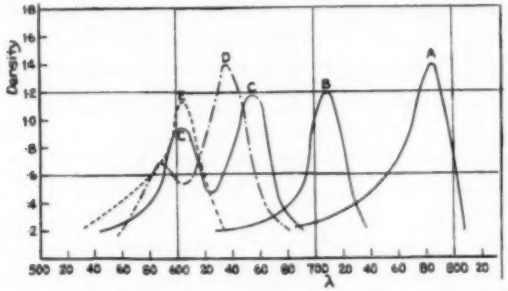

FIG. 6. *Absorption curves of red and infrared sensitizing dyes.*

A—Neocyanine	1 : 200,000
B—Kryptocyanine	1 : 400,000
C—Dicyanine	1 : 200,000
D—Naphthocyanol	1 : 200,000
E—Pinacyanol	1 : 400,000

neglible since excellent agreement has always been secured when comparing the photographic determinations with those made by visual or radiometric methods. In addition we are indebted to S. B. Nicholson and E. Pettit[11] of Mount Wilson Observatory for data on the transparency of calcite showing that it is quite nonselective to wave length 2000 mμ.

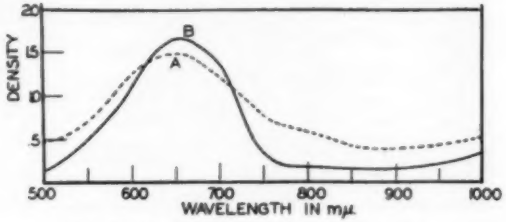

FIG. 7. *Absorption curves of typical blue dyes.*
A=Anthraquinone Blue S·R Extra-Badische 1/2000, H_2O, 1 cm cell
B=Toluidine Blue Hoechst 1/10,000, H_2O, 1 cm cell

In Fig. 6 the absorption curves of five dyes used in sensitizing emulsions for the red and infrared are plotted from data obtained in the above manner. They are of considerable interest in that they show a

[11] Nicholson, S. B., and Pettit, E., Physical Rev., *22*, p. 199, and additional unpublished information furnished by the authors.

correlation between the absorption band and region of maximum sensitizing.[12] Results from previous tests made to obtain the wave length of maximum absorption by radiometric methods were unsatisfactory, at

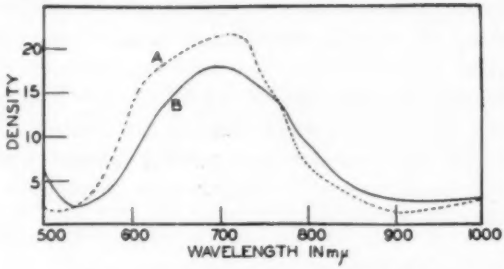

FIG. 8. *Absorption curves of typical green dyes.*
B=Naphthol Green=Hoechst 1/10,000, H_2O, 1 cm cell A=Filter Blue Green 1/10,000, H_2O, 1 cm cell

least for the concentration of dye which it was desired to use since the energy transmitted near the peaks of the absorption bands was entirely too small for accurate measurement.

Typical green and blue dyes have the absorption curves shown in Figs. 7 and 8 and several Wratten filters made for invisible signaling

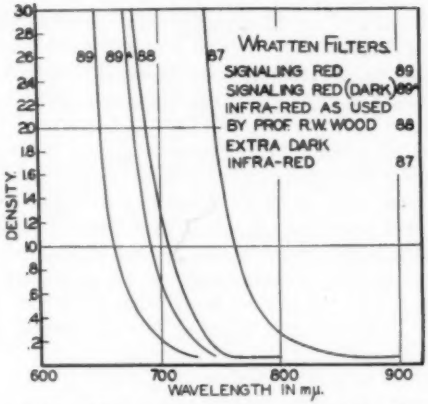

FIG. 9. *Absorption curves of Wratten red and infrared filters.*

purposes, and photography by infrared radiations[13] are shown in Fig. 9. For maximum efficiency in photographing with infrared rays it is neces-

[12] Dundon, M. L., Color Sensitizing Photographic Plates by Bathing. Amer. Photog., Dec., 1926.

[13] Mees, C. E. K., The Color Sensitivity of Photographic Materials, J. Frank. Inst., *201*, p. 545; 1926.

sary to use filters having sharp cuts, i. e. steep absorption curves on the infrared side of the absorption band. From our investigations so far we have found that a solution of Neocyanine in combination with a No. 87 Wratten filter to absorb the visible and ultraviolet rays serves well for making photographs by infrared radiation from wave length 800 to 900 mμ.

In conclusion it appears that the method is free from most of the objections to a photographic method and in combination with methods previously described in the literature permits the use of photographic plates for spectrophotometric measurements throughout the region extending from 200 to 900 mμ.

EASTMAN KODAK CO.,
ROCHESTER, NEW YORK.

Quarter-wave Plates.—In using a quarter-wave plate of mica it is often important to know which of the two principal directions corresponds to the greater retardation. This point has been generally neglected by text-books, and the author has found mention of methods in only two text-books, namely: Wood's "Physical Optics," and Tutton's "Crystallography." Because of its simplicity, the method described in Tutton's "Crystallography" will now be called attention to. The method is as follows.

The quarter-wave plate is placed between crossed nicols with its plane perpendicular to the axis of the beam of incident white light and in an azimuth such that the restored light is a maximum. The principal directions in the plate now make angles of 45° with the planes of vibration of the nicols. The plate should then be rotated—first round one principal direction, then around the other as axes, so that the light traverses a thicker layer of mica. In one case the color passes from bluish grey through iron gray to black, and in the other case through white to yellow and to interference colors of a higher order. The latter corresponds to rotation about the direction parallel to the slower vibration, and the first case to the perpendicular direction of faster vibrations.

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A GLASS WATER STILL

By G. G. Kretchmar

ABSTRACT

A glass distilling apparatus for water is described. It consists of a Pyrex flask attached to a condenser of the same material in such a way that the water level is maintained during operation. The heater is a 600 watt element made of nickel-chromium wire and directly immersed in the water. The capacity is about 700 cc per hour. The operation is automatic and the efficiency is about 85 per cent.

A distilling apparatus for producing distilled water of high purity may be easily constructed in any laboratory possessing a simple glass-blowing outfit. This apparatus is very satisfactory for the small laboratory and since it can operate continuously without attention may also be found useful in places where a considerable quantity of distilled water is required.

Fig. 1 shows the constructional features of the device. The glass parts are of Pyrex glass. The bulb is conveniently made of a 500 cc flask with a round bottom. The condenser is about 12 inches long and the flask is rigidly attached to the condenser by means of the tube T, which serves as the inlet for maintaining the water level in the flask. The whole apparatus is mounted on a base of hard wood by means of small wooden supports extending out from the base and strips of sheet brass around the glass in three places. These supports are suggested in the shaded sections of the diagram.

For the position of the overflow tube O, as shown, the average water level will be approximately along the line AA. The tube T is attached to the condenser so that its top is about the same level as the bottom of the overflow tube. This will assure a good supply of water from the top of the condenser where it has been preheated by the condensing steam.

The condenser tube is sealed to the neck of the flask in about the position shown. It is held in place in the condenser by means of a cork stopper C at the top and a tight rubber connection R at the bottom. The cork stopper C has a hole bored through it to allow access of air to the top of the condenser and thus prevent a syphon from forming in the overflow tube which would, if it should form, draw the water out of the flask.

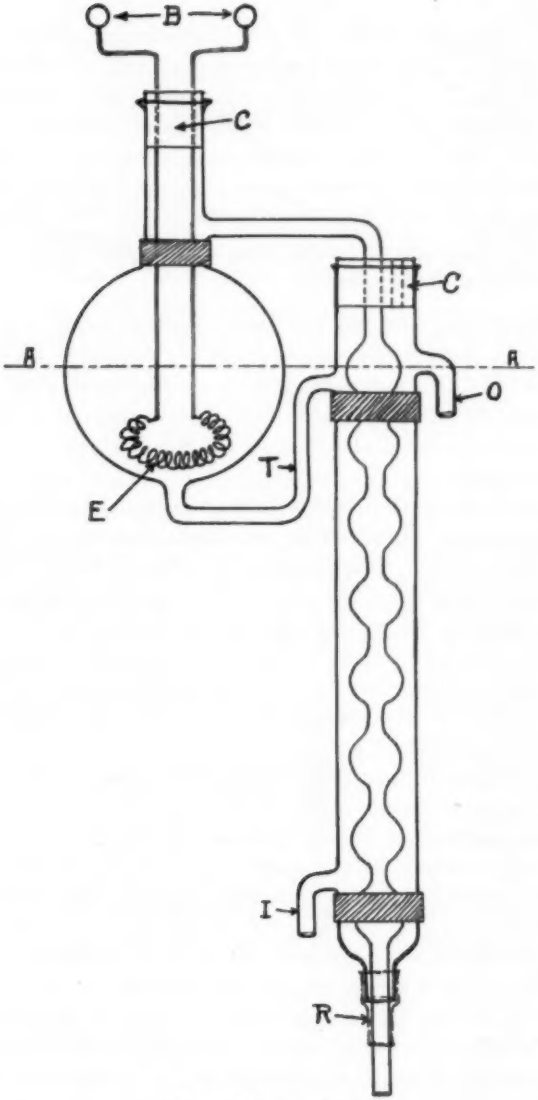

FIG. 1. *A glass water still.*

The heating element is made of four feet of number 30 Chromel A or any similar alloy, wound in the form of a spiral about 5 mm in diameter. The ends are fused to leads of the same material of about number 14 wire, by means of a small electric arc. The spiral is weighted down with small pieces of glass tubing. The leads pass through a cork stopper *C* and are held in place by the two binding posts *B*. These posts also serve for attachment to any 110 volt circuit. The heater takes about 600 watts on a 110 volt circuit. The heating coil is easily removed whenever it becomes necessary to clean out the sediment from the flask.

DEPARTMENT OF PHYSICS,
WALLA WALLA COLLEGE,
COLLEGE PLACE, WASHINGTON.

Magnetism and Atomic Structure. By Edmund C. Stoner, Ph.D., Lecturer in Physics at the University of Leeds. xiii+371 pages. E. P. Dutton and Company, New York. $5.00.

An account of magnetic phenomena and of the attempts to interpret them in terms of the quantum theory. The treatment is semi-historical, but, in the interest of brevity, the author has of necessity passed over, frequently with but brief reference, the fundamentals of magnetism usually found in standard treatises, and has aimed "to give the reader a general and balanced account of the present state of the subject, and to enable him to follow its subsequent development."

Among the captions of the sixteen chapters may be mentioned: The Interpretation of Magnetism as an Atomic Phenomenon; The Quantum Theory; The Gyromagnetic Effect; The Magnetic Deviation of Atomic Rays; The Zeeman Effect; Diamagnetism; Magnetism and the Structure of the Atom; Magnetism and Chemistry.

In spite of the kaleidoscopic developments in modern physics, a book of this kind will find a permanent place among the important treatises on the subject. Dr. Stoner has combined a discussion of both experiment and theory in a way which should prove very valuable for the student who wishes to become familiar with this increasingly important branch of physics.

[F. K. R.]

Introduction to Contemporary Physics. By Karl K. Darrow. xxvi+453 pages. D. Van Nostrand Company. New York. $6.00.

This volume is based upon, *but is not merely a reprint of*, the very interesting series of articles by the author which have appeared since 1923 in the Bell System Technical Journal. Certain parts of those articles have been omitted, and much new material, "amounting to nearly half of the volume," has been inserted. The result is a very readable, up-to-date account of this rapidly growing subject. An extract from the preface gives the viewpoint from which the author has written. "The fact is," he writes, "that the body of recorded phenomena constituting physics changes comparatively slowly, and nearly always by augmentation; while the current views as to the most expedient and satisfactory models for imitating these phenomena change at times . . . . with bewildering rapidity. The data of physics are permanent, but at any moment they are liable to be restated in new ways. . . . ."

The book is divided into thirteen chapters. Chapters I and II present, respectively, the experimental electron and the experimental atom; that is to say, the properties of these particles as determined unambiguously by experiment. Chapter III discusses the periodic table and the regular arrangement of the properties, periodic and non-periodic, of the elements. Chapters IV and V take up, in turn, the deflection of alpha-particles and of electrons by atoms, as the experimental introduction to the nuclear atom-model. A most delightful discussion of "Waves and Quanta," Chapter VI, ends with this statement: "Our descendants may think of us and our perplexity (as between waves or quanta) with an amused wonderment as we of our ancestors, who could not comprehend how a man can stand upright at the antipodes." Chapter VII, under the caption "Ionization," discusses such topics as ionization potentials, photoelectric effect of x-rays, etc. Chapters VIII, IX and X deal with spectroscopy in its various phases. Atom models occupy Chapters XI and XII. The last chapter is devoted to the conduction of electricity in gases.

Throughout the book Dr. Darrow has maintained a highly commendable conservative attitude, yet he has presented the most recent and advanced views. He has added just enough of the "philosophy" of the subject to raise the book above the level of most books of its kind. And the happy way in which he has summarized both theory and experiment makes the book valuable for both the critical student and the general reader.

[F. K. R.]